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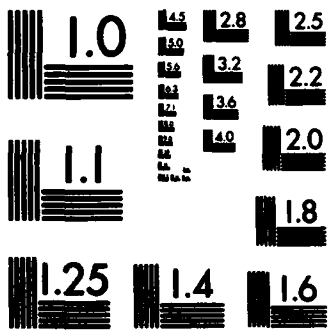

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

CONTROL SYSTEM TEST VEHICLE (CSTV) SEAKEEPING ENVIRONMENT SUITABILITY AND OPERATIONAL GUIDELINES

By

MARTIN J. DIPPER

and

MICHAEL J. DAVIS

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FEBRUARY 1983 SPD - 1073 - 01

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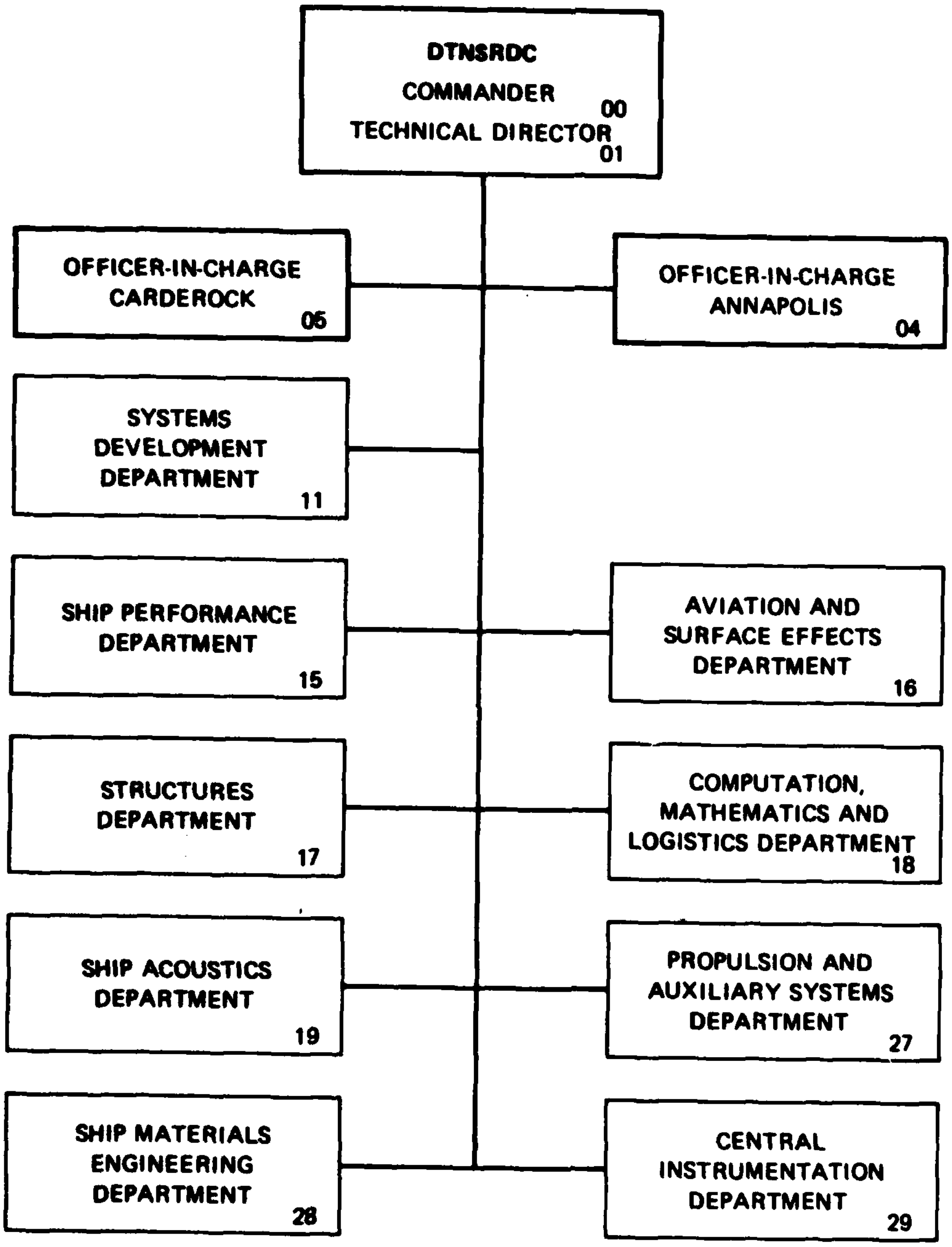

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER SPD - 1073 - 01	2. GOVT ACCESSION NO. AD-A133 857	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CONTROL SYSTEM TEST VEHICLE (CSTV) SEAKEEPING ENVIRONMENT SUITABILITY AND OPERATIONAL GUIDELINES		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) MARTIN J. DIPPER and MICHAEL J. DAVIS		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Ship Performance Department David Taylor Naval Ship R&D Center Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project Area: 63561N Task Area: S0207AS Work Unit No.: 1-1562-103
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE FEBRUARY 1983 13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Directional Wave Spectra, Submarine Seakeeping

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An evaluation of the suitability of the seaways that can be expected during CSTV operation in the Gulf of Mexico off of Panama City, Florida, is presented. Representative wave spectra from this area are presented which compare favorably with open ocean spectra and theoretical spectrum formulations. The problems which multidirectional seaways present to seakeeping trials are discussed and guidelines are presented to deal with operation in such seaways. General guidelines for conducting seakeeping trials are also given.

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ABSTRACT

An evaluation of the suitability of the seaways that can be expected during CSTV operation in the Gulf of Mexico off of Panama City, Florida is presented. Representative wave spectra from this area are presented which compare favorably with open ocean spectra and theoretical spectrum formulations. The problems which multidirectional seaways present to seakeeping trials are discussed and guidelines are presented to deal with operation in such seaways. General guidelines for conducting seakeeping trials are also given.

ADMINISTRATIVE INFORMATION

This work was sponsored by the Naval Sea Systems Command under the Advanced Submarine Control Program, Project Area 63561N and Task Area S0207AS as David Taylor Naval Ship R&D Center Work Unit Number 1-1562-103.

INTRODUCTION

The dynamic responses experienced by marine vehicles in a seaway, such as accelerations, motions, and wave induced forces and moments, can be examined experimentally through modeling techniques. The Control System Test Vehicle (CSTV) is an experimental model submarine used by the Navy's Advanced Submarine Control Program (ASCOP) for research in the area of submarine dynamics and control. The purpose of this vehicle is to serve as a model capable of performing free-running realistic maneuvers allowing the investigation of all modes of dynamic behavior (1)*. One goal of ASCOP has been to investigate the dynamic performance of submersibles operating on or near the surface in open waters. The prediction of full scale submarine response from CSTV experimental data collected in waves requires a determination that the model test environment is representative of the anticipated full scale environment. This determination is the subject of this investigation.

The CSTV is currently operated in the Gulf of Mexico off of Panama City, Florida in the vicinity of the Naval Coastal Systems Center's (NCSC) Environmental Monitoring System (EMS). The EMS can be used to quantitatively characterize the Gulf environment in which the CSTV can perform surface and near surface maneuvers. Existing CSTV technology is capable of monitoring primary vehicle parameters fundamental to seakeeping and maneuvering evaluation. Determination of the vehicle operating environment, vehicle motions and accelerations allows an assessment of vehicle performance in seakeeping and maneuvering. In order to achieve this assessment the Gulf sea spectrum must be shown to be representative of the anticipated full scale environment. This report addresses this qualification through the following objectives:

- Perform seaway analyses to characterize typical seaways in which the CSTV operates.
- Evaluate the suitability of these ambient seaways for modeling full scale sea states.
- Qualify in terms of spacial and temporal stationarity the application of seaways encountered at Panama City to determining CSTV response.
- Identify the importance of directional seaway analysis in determining the CSTV response for operations on the surface in open waters.
- Establish general guidelines for vehicle operation, conducive to the determination of vehicle response, given existing monitoring capabilities.

* Numbers in parentheses refer to references listed at end of report.

ENVIRONMENT

Gulf Environment and Measured Wave Spectra

The model environment to be evaluated for CSTV operations includes the Gulf of Mexico waters off of Panama City, Florida in the vicinity of the EMS offshore platforms, stages 1 and 2. Figure 1 is a chart of the Gulf showing the stage locations and bottom contours. The remote sensing systems of the stages are capable of providing wave time histories, current speed, and wind speed and direction. There is an existing telemetry data link between the EMS stages and NCSC which when coupled with the NCSC real-time spectral analyzer is capable of real-time wave spectral analysis. This capability permits identification of a wave environment immediately prior to an experimental vehicle task. An on-line desk top computer at NCSC provides periodic summaries of wave, wind, and current data. More extensive analysis programs for wave data are available at NCSC. Software exists at NCSC and DTNSRDC that allows DTNSRDC to perform complete qualification and analysis of EMS data recorded by NCSC. These analyses include: significant wave height, wind speed, wind direction, qualification of seaway spaciotemporal stationarity, point wave spectra, and directional wave spectra.

From past work with the EMS at DTNSRDC, a large sample of environmental data has been compiled characterizing the Gulf seaway in the area of proposed CSTV operation (2). Data analysis has been performed on these data to determine wave stationarity, and wave point and directional spectra. To evaluate the suitability of these seaways for modeling full scale sea states, the spectral properties of the Gulf wave data are presented in effective full scale units in Appendix A using the CSTV scale ratio of 1:12. Wave height is scaled directly as the linear scale ratio. Power density is scaled as the square of the scale ratio. And, frequency is scaled as the square root of the scale ratio. The effective full scale range of sea states presented in appendix A includes sea states 3 through 8. These sea state level designations are based only on the measured significant wave height.

A detailed explanation of the data analysis procedures and techniques applied to the Gulf wave data is available in reference 2. The length of time to be analyzed was determined using the run test (as described in detail in reference 3) to determine the temporal stationarity of the wave data mean and standard deviation values.

Table 1 is a sea state chart indicating the range of significant wave heights and associated sea state levels for both the actual measured seaway and the effective full scale seaway. A comparison of measured and effective full scale sea states shows that the measured seaway must be of a sea state 0 to sea state 2 to obtain an effective full scale seaway

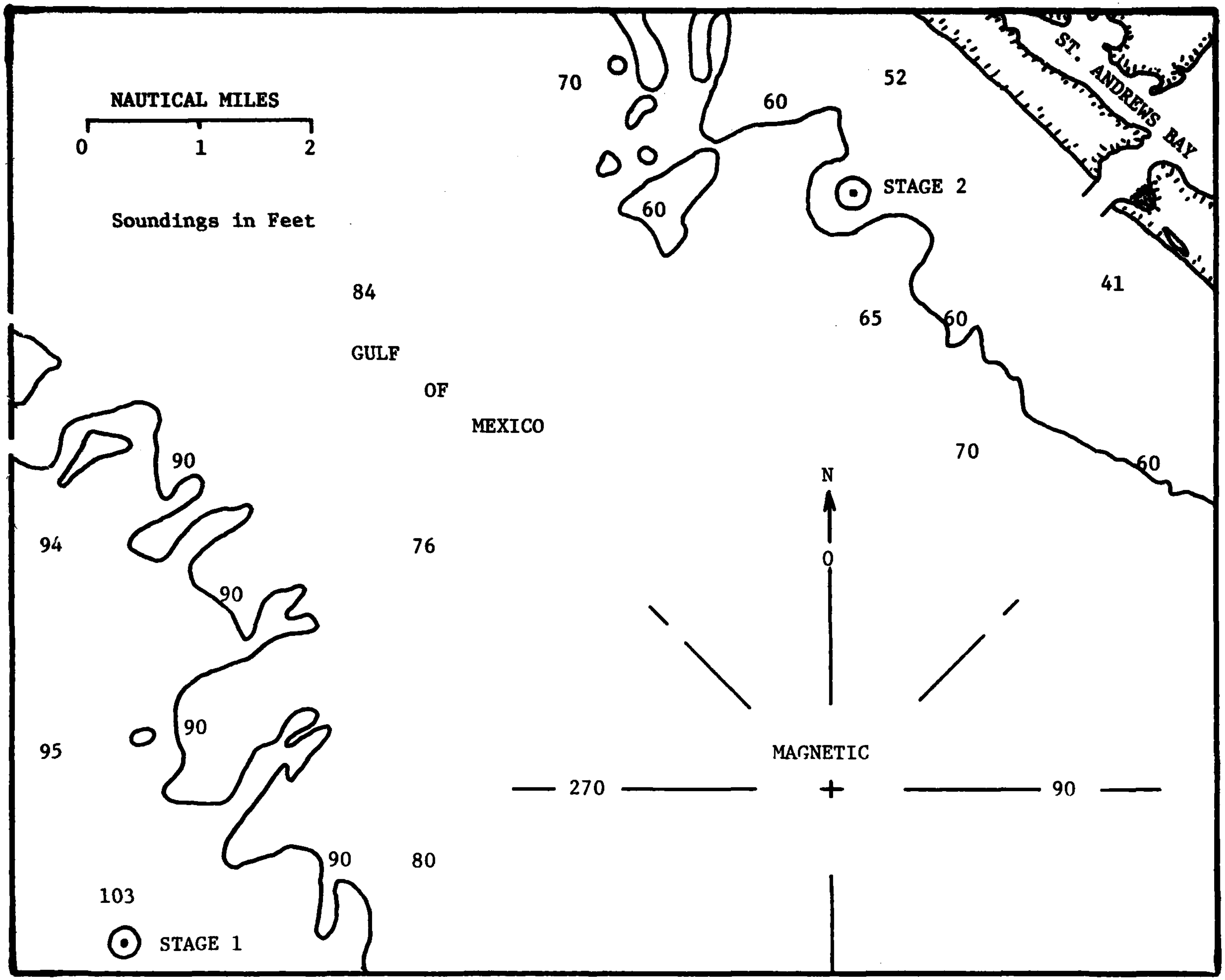


Figure 1. CSTV Test Area at the Naval Coastal Systems Center

TABLE 1 SEA STATE CHART

ACTUAL MODEL SCALE SEAWAY			EFFECTIVE FULL SCALE SEAWAY		
Sea State	Significant Wave Height (feet)	Significant Wave Height (meters)	Significant Wave Height (meters)	Significant Wave Height (feet)	Sea State
0	0.00	0.00	0.00	0.00	0
	0.007	0.002	0.02	0.07	
	0.03	0.01	0.09	0.30	1
	0.10	0.03	0.31	1.00	
1	0.13	0.04	0.43	1.40	2
	0.23	0.07	0.88	2.90	
	0.26	0.08	1.01	3.30	3
	0.39	0.12	1.40	4.60	
	0.52	0.16	1.86	6.10	4
	0.59	0.18	2.10	6.90	
	0.66	0.20	2.44	8.00	5
	1.00	0.31	3.66	12.00	
2	1.08	0.33	3.96	13.00	6
	1.50	0.46	5.50	18.00	
	1.84	0.56	6.70	22.00	7
	2.92	0.89	10.67	35.00	
3	3.35	1.02	12.20	40.00	
	3.74	1.14	13.70	45.00	8
	4.17	1.27	15.25	50.00	
4	4.82	1.47	17.70	58.00	
	5.35	1.63	19.50	64.00	9
	6.92	2.11	25.30	83.00	

between sea state 0 and sea state 8. EMS measurement capability is limited to measurement of wave amplitudes of 0.152m (0.5 ft) or greater(4). Due to this limitation, the lowest sea state presented in this report is an effective full scale sea state of a high state 3. This limitation could be removed by replacement of the EMS wave measurement instrumentation.

From linear wave theory (5), using the ratio of effective water depth (d) to predominant effective wavelength (λ), the Gulf seaway can be classified as a shallow, transitional or deep water seaway (5).

Shallow	Transitional	Deep
$d/\lambda \leq 1/25$	$1/25 < d/\lambda < 1/2$	$1/2 \leq d/\lambda$

To classify the measured wave conditions in the Gulf, the effective wavelength (λ) is computed at the wave period (T) of the peak amplitude of the effective wave spectra for the equivalent full scale depth (d), using the following equation:

$$\lambda = \frac{gT^2}{2\pi} \tanh \frac{2\pi d}{\lambda}$$

Since λ is present on both sides of this equation an iterative solution or the use of tables such as those in reference 5 must be used to determine λ. Effective seaway depth information for the Gulf environment is presented in Table 2 which covers the range of sea states sampled at EMS stages 1 and 2. The effective seaway depth at stage 1 is essentially transitional. The effective seaway depth at stage 2 varies from shallow to transitional.

Inspection of the Gulf wave spectra plots presented in appendix A indicates the existence of a secondary spectral peak at a low frequency in a number of seaways encountered at stage 2. Figure 2 is an example of a wave spectra plot with such a secondary spectral peak. Table 2 summarizes the existence of this secondary spectral peak in seaways encountered at stages 1 and 2. No secondary, low frequency, wave spectra peaks were observed at the offshore stage, stage 1. Sixty percent of the nearshore stage 2, wave data did exhibit a secondary, low frequency peak.

Directional wave spectra plots associated with the Gulf point (single wave gage) wave spectra plots (Appendix A) are presented in Appendix B. The three dimensional wave spectra plots indicate the predominate wave direction at the EMS stages for the sample of sea states encountered.

TABLE 2 SUMMARY OF GULF OF MEXICO FULL SCALE SEAWAY CHARACTERISTICS

Run No. and Run Time	Sea State	Existence of Secondary Spectral Peak		Wavelength at Primary Peak Spectral Frequency				Effective Seaway Depth (Linear Wave Theory)	
		Stage 1	Stage 2	Stage 1 (m)	Stage 1 (ft)	Stage 2 (m)	Stage 2 (ft)	Stage 1	Stage 2
1600: 380-3800	3	No	-	290	953	-	-	Transitional	-
1: 2000-6000	4	-	Yes	-	-	678	2225	-	Shallow
21600: 0-6000	5	No	-	250	821	-	-	Transitional	-
21600: 6001-14175	5	-	No	-	-	250	821	-	Transitional
11900: 1956-3756	6	-	Yes	-	-	143	470	-	Transitional
4100: 69-1854	7	-	Yes	-	-	1141	3743	-	Shallow
4900: 3054-4448	7	No	-	233	766	-	-	Transitional	-
11700: 6767-10367	7	-	No	-	-	170	557	-	Transitional
3: 0-7292	8	No	-	866	2841	-	-	Shallow	-

Run No.: 1 : 2000.0 - 6000.0

Wave Height Spectrum

Stage 2

North Probe

Sea State 4 M

Sig. DA: 1.90 M

Amp. Max.: .635

Freq Max.: .780

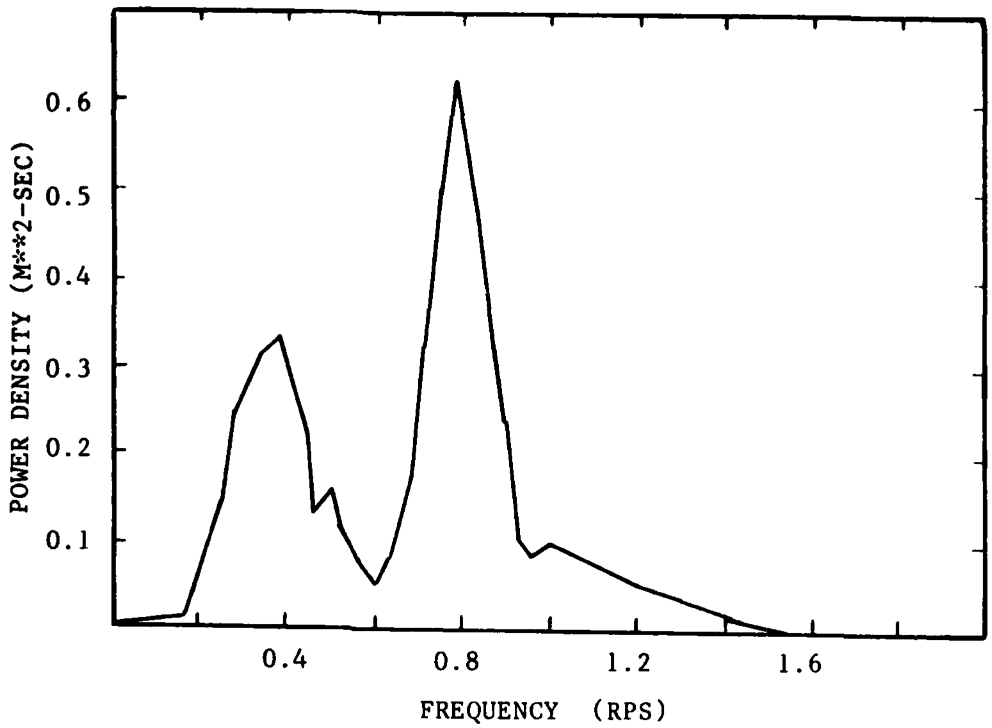


Figure 2. Gulf of Mexico Wave Height Spectrum Demonstrating a Low Frequency Secondary Spectral Peak

Accurate definition of wave direction through directional spectral analysis requires simultaneous collection of wave data from an array of three or more wave height probes. Verification of stationarity in the seaway and determination of point spectra for each wave height probe is essential in calculating a resultant directional wave spectrum. Each EMS stage is equipped with an array of four wave height probes. Both, the point wave spectrum for each of the wave height probes in a stage array and the directional spectrum of a stage array are cataloged by run number and relative time period. The run number, time period and stage number should be used in drawing comparisons between individual point spectra and the resultant directional spectrum presented in Appendices A and B, respectively.

Inspection of the Gulf directional wave spectrum plots shows that the seaways in the vicinities of both stages 1 and 2 are generally multidirectional. The higher and more fully developed seaway, demonstrates less directional scatter as predominate wave energy is concentrated within a 90 degree quadrant. The lower sea state, developing seaway, demonstrates less directional definition.

The nearshore seaway, in the vicinity of stage 2, contains wave energy propagating typically from the southern quadrant. This onshore propagation influences the character of the stage 2 seaway as indicated by the secondary, low frequency, spectral peak of the point wave spectra. This low frequency peak is probably due to the decrease in water depth between stages 1 and 2. Figure 1 shows that both the stage 2 and stage 1 environment are fetch limited in the northern directional quadrants. There is less directional limitation observed in the offshore stage 1 environment.

Measured Ocean Spectra

A sample of measured ocean wave data from the North Atlantic weather station INDIA is presented in Appendix C; and is representative of a typical environment in which the full scale submersible is expected to operate. Station INDIA data collection and analysis procedures, and sea state data are documented in reference (6). The sample of INDIA wave data presented in this report corresponds to the Gulf data presented for a range of sea states selected on the basis of significant wave height and modal period. This allows comparison of the anticipated full scale ocean environment with the proposed Gulf model environment. Unfortunately no directional wave information is available in the INDIA data or in any other published summary.

Station INDIA is a site in the North Atlantic at 59°N, 19°W where weather ships have been deployed to monitor the ocean environment. Applying the same criteria used to classify the effective water depth of the Gulf environment, this particular ocean environment is defined as deep water. Inspection of the ocean wave spectra plots presented in Appendix C demonstrates the existence of multiple peak spectra in the deep water ocean environment. However, in this sample of ocean data, there are no secondary spectral peaks at frequencies as low as those encountered in the Gulf, stage 2, data. The stage 2 data demonstrates the influence of the shoreline on the seaway. This influence is of course, absent from the sample of deep water ocean data. The stage 1 data is more representative of the deep water ocean environment than the stage 2 data, based on wave spectra content.

Theoretical Spectral Formulations

The Pierson-Moskowitz and Bretschneider theoretical wave spectra formulations are presented for comparison in this report as representative theoretical wave spectra which might be used in model basin or simulation evaluations. These spectral formulations describe deep water, fully developed seaways and are expressed as follows (7):

Pierson-Moskowitz Spectrum

$$S(\omega) = \frac{8.1}{10^3} \frac{g^2}{\omega^5} e^{-0.032 \frac{g^2}{\zeta^2 \omega^4}}$$

where, $s(\omega)$ = spectral density function

g = gravity constant

ω = wave frequency in radians/second

ζ = significant wave height

Bretschneider Spectrum

$$S(\omega) = \frac{1.25}{4} \frac{\omega_m^4}{\omega^5} \zeta^2 e^{-1.25 \frac{\omega_m^4}{\omega^4}}$$

where, ω_m = modal wave frequency in radians/second

These spectral formulations are recommended by the International Towing Tank Conference (ITTC) and the International Ship Structure Committee (ISSC).

As demonstrated by the wave spectra plots of Appendices A and C, the shapes of measured wave spectra vary considerably even when the significant wave heights are the same. This variation in shape is dependent upon environmental conditions such as geographic location, duration and fetch of the prevailing wind, stage of growth and decay of a storm, existence of swell, etc. (7). The theoretical wave spectra formulations can not easily encompass all of these environmental influences, and consequently reflect greater smoothness in spectral shape at a given sea state.

Comparison of Gulf, Ocean and Theoretical Environments

Comparisons of Gulf of Mexico, Ocean Station INDIA and theoretical seaway statistical properties and wave spectra plots are presented in Appendix D. The graphic overlays of the wave spectra plots presented in Appendix D are used to identify similarities and differences in spectral shape between the effective full scale Gulf seaway and the anticipated full scale ocean seaway. The approximation inherent in modeling the ocean environment using these generally accepted theoretical spectra is apparent in these plots which compare the measured spectra with the theoretical.

For the high sea states (6,7,8) there is good to excellent comparability of Gulf stages 1 and 2, ocean station INDIA, Pierson-Moskowitz and Bretschneider wave spectra shapes. These high sea states demonstrate the best comparability. For the medium sea states (3,4,5), comparison of

Gulf, ocean and theoretical seaways is more variable. The Pierson-Moskowitz spectra do not compare with either the Gulf or ocean wave spectra over this range of medium sea states. The Bretschneider theoretical spectra show good comparability with the Gulf stage 1 and ocean spectra for medium sea states. However, the stage 2 data again exhibit a secondary, low frequency, spectral peak, not characteristic of the INDIA wave spectra. For the low sea states (0,1,2), no Gulf EMS stage data were available due to limitations in currently implemented wave measurement instrumentation. Consequently, no seaway qualification was attempted for this sea state range.

METHODS OF EVALUATING CSTV SEAKEEPING

Methods of evaluating vehicle response are dependent upon measurement of external conditions causing vehicle motions and measurement of the resultant vehicle motions. Figure 3 depicts the significant external conditions acting on a submarine operating on the surface. These external conditions, coupled with the depicted submarine propulsion and control forces, determine the motion of the submarine. This report is primarily concerned with the effects of the seaway, which for most surface operations is the most significant external condition. Wind, water and current must also be measured and can be similarly analyzed when necessary.

When conducting model scale investigations such as those performed with the CSTV, the general practice is to operate the vehicle in seaways similar to those expected during full scale operation. When the spectral characteristics of the actual full scale seaway are not known, the usual procedure is to use theoretical spectral formulations, which provide a reasonably good approximation of the expected operational seaways. As previously shown, the seaways in which CSTV operates when scaled to expected full scale operation provide good approximations to both: recorded full scale (Station INDIA) seaways, and accepted theoretical formulations from the point of view of spectra measured at a point.

The goal of seaway measurements is to quantify the seaway acting on the vehicle and to use this in combination with the recorded vehicle motion to evaluate the vehicle's performance. Ship performance is generally characterized through linear motion response amplitude operators (or transfer functions) as depicted in Figure 3. These quantities are presented as the square root of motion divided by excitation amplitude in order to provide a normalized measure of vehicle response. For the case of a linear system and a unidirectional seaway these quantities are relatively easily calculated and comparable from case to case (Figure 4b). However, for a multidirectional seaway, calculation of these values is generally of little use

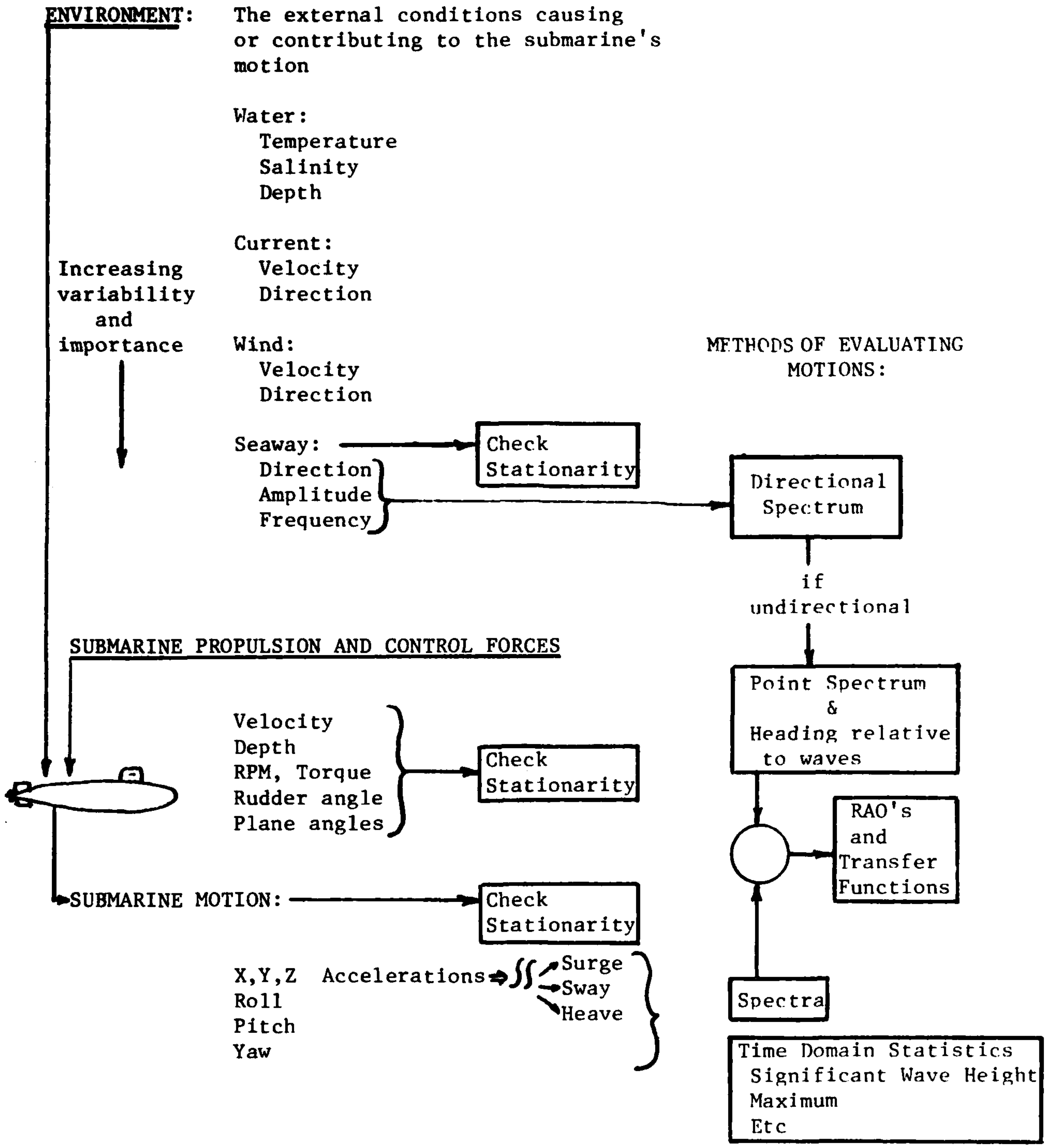
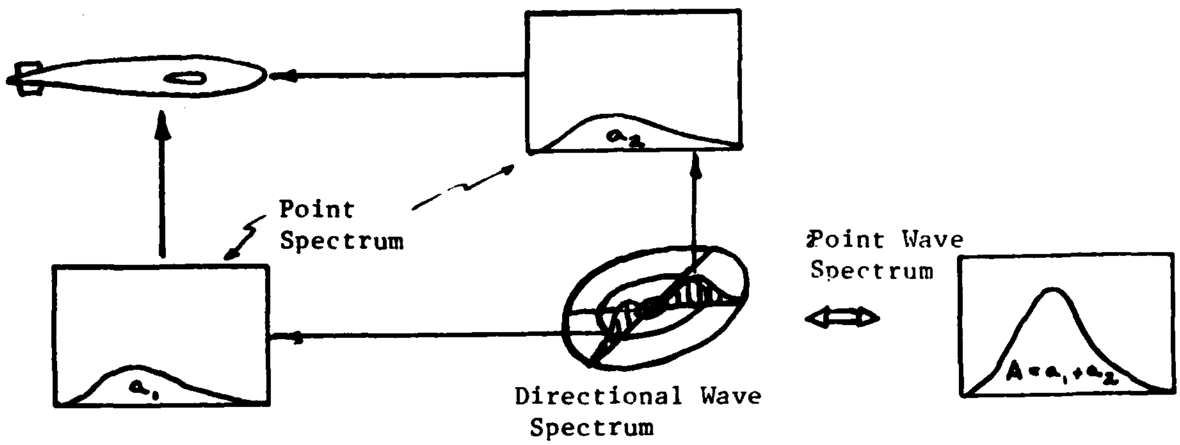
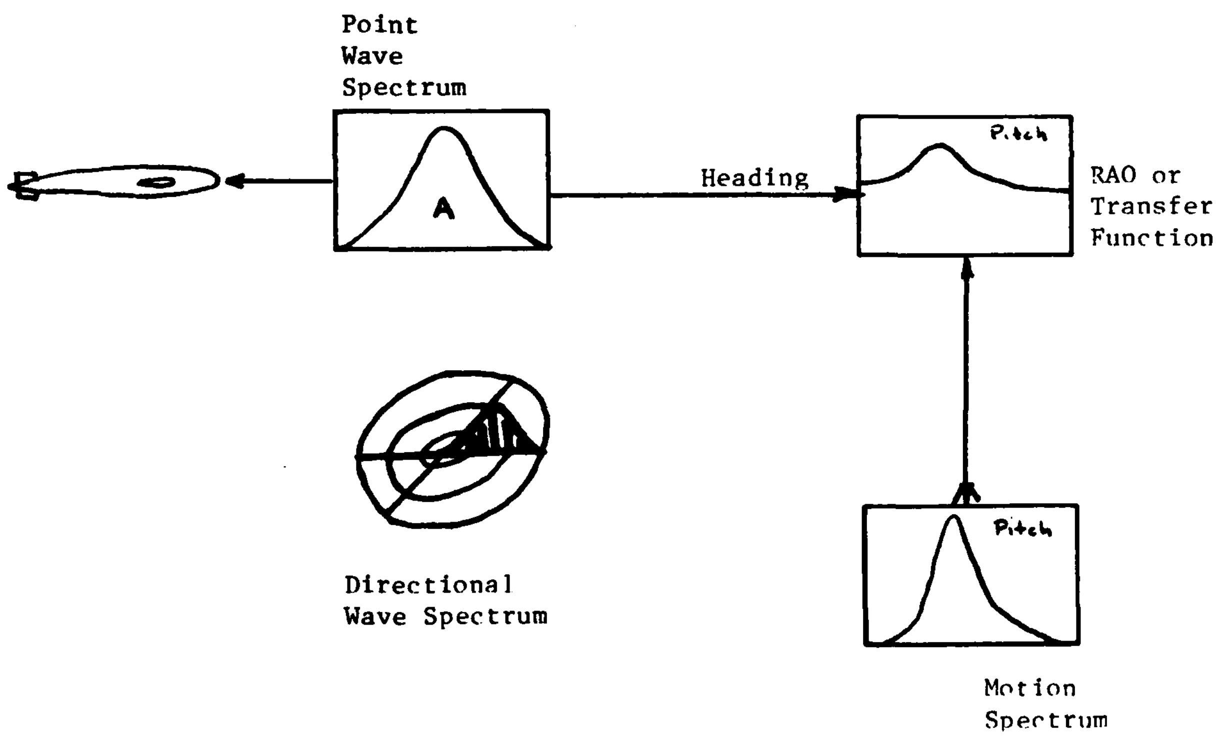


Figure 3. Submarine Operating on the Surface in Open Waters



(a) Multi-Directional Case - Simplified



(b) Unidirectional Case

Figure 4. Importance of Directional Measurement in the Seaway

because the results are comparable only to another seaway with identical amplitude and directional properties (The directional measurement should be made in any case to avoid a situation such as that in Figure 4a, a multi-directional seaway, being mistaken for one such as that in 4b, a unidirectional seaway). Nor can the directional spectrum measurements be used directly to overcome this problem. The exception to this last statement would be that if the vehicle's response to waves from any direction (i.e. the vehicle's directional transfer functions) are known well enough, then the response amplitude operators or transfer functions for unidirectional seaways could be calculated. This same problem exists whenever real seaway data, which are seldom truly unidirectional, are compared to unidirectional simulation or model basin data. The best that can be done in a multi-directional seaway is to measure the directional wave characteristics and present a directional wave spectrum as data which qualify the seaway which existed during the recorded motions.

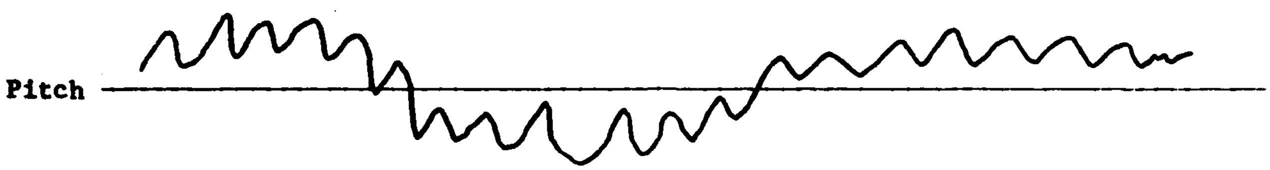
In either the unidirectional or multidirectional seaway cases discussed above the seaway, propulsion and control forces, vehicle heading, and the resulting motions must be checked for stationarity as depicted in Figure 3. This check assures that the measured motions are due solely to either random forces such as the seaway or to particular variables such as control inputs which are changing in a planned manner, and not due to some other unanticipated force (either internal or external as detailed in Figure 5). Stationarity can be easily checked by applying the run test described in reference 3 to the mean and standard deviation values of the measured data.

OPERATIONAL PROCEDURE

A complete operational procedure and a discussion of associated problems is given in Appendix E. The recommended procedure may be summarized as follows:

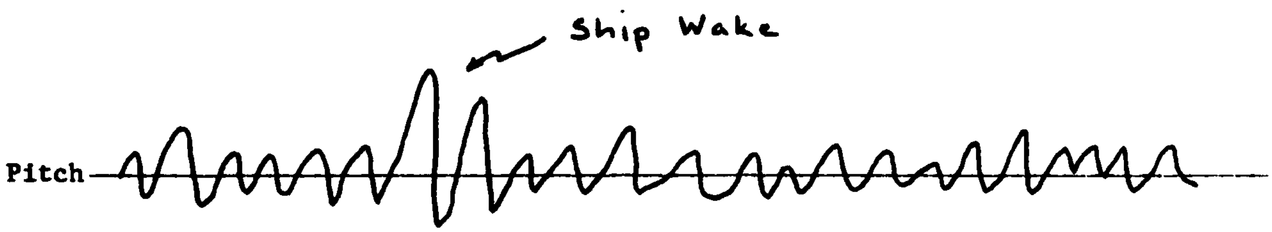
- Evaluate spectral characteristics of seaway to determine amount of time data needs to be collected.
- Evaluate seaway directionality.
- Evaluate spacial and temporal stationarity of wave data.
- Collect data, as required by above, for several headings to seaway, varying only those parameters being evaluated as variables (if any).
- Evaluate temporal stationarity of all motion and control data.
- If seaway is unidirectional, calculate response amplitude operators and/or transfer functions.
- If seaway is not unidirectional compute statistical motion response characteristics and designate their applicability only to the specific full scale seaway encountered.

Example of Data with Non-Stationarity Mean



This sort of data might be expected for a sub on the surface in waves making a very shallow dive and then returning to the surface, but would not be acceptable for a sub operating on the surface because in addition to the action of the waves on the sub you are measuring the effect of the diving planes (i.e., for surface operation you would like to determine the effect of the waves. The simplest way to do this is to eliminate as many other variables as possible).

Example of Data with a Non-Stationarity Standard Deviation



A transient event, such as a ship wake, should not be included in the measurement of the effect of a random seaway on the surfaced submarine.

Figure 5. Example of Seaway Spatiotemporal Stationarity

CONCLUSIONS

- The seaways which can be expected at Panama City during the operation of the CSTV, in most cases, provide a good approximation in terms of amplitude and frequency to full scale seaways, and to theoretical seaways generally used in model evaluations. For the high sea states (6, 7, and 8 full scale) there is good to excellent comparability of Gulf stages 1 and 2, Ocean Station INDIA, Pierson-Moskowitz, and Bretschneider wave spectra shapes. For the medium sea states (3, 4, and 5 full scale), comparison of Gulf, ocean, and theoretical seaways is more variable. Over this medium range of sea states the Gulf and station INDIA spectra do not compare well with the Pierson-Moskowitz theoretical formulation. The Gulf stage 1 and Station INDIA spectra do compare well with the Bretschneider spectral formulation. The Gulf stage 2 spectra, for this range or sea states, exhibit a secondary, low frequency peak in the spectra, not characteristic of the Station INDIA wave spectra.

- The current Environmental Monitoring System wave height transducers limit the lowest equivalent full scale seaway that CSTV operation can simulate to a high sea state 3 (significant wave height approximately 1.83M (6 ft). The measurement of equivalent full scale sea states lower than this will require other methods of wave height measurement.

- The low sea states (0 to 3) required for the CSTV model to simulate the full scale operation of a submarine are generally not unidirectional. This multidirectionality presents an analysis and comparison problem, which exists when comparing any full scale or real world vehicle to tank model or computer simulation results.

- Full scale response may be determined for tests in unidirectional seas in terms of response amplitude operators similar to those developed through model tank testing.

- Full scale response in directional sea conditions can be reported only for the specific directional seaway encountered and published.

- The procedures delineated in this paper provide a means of quantifying the seaway conditions and qualifying the randomness of those vehicle motions which would be expected to be random in a random seaway. Ship control generated responses must be removed from the measured motion or otherwise included in the analysis.

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APPENDIX A

Gulf of Mexico Wave Spectra Plots and Statistics

GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 1600 : 380.0 - 3800.0

Wave Height Spectrum

Stage 1

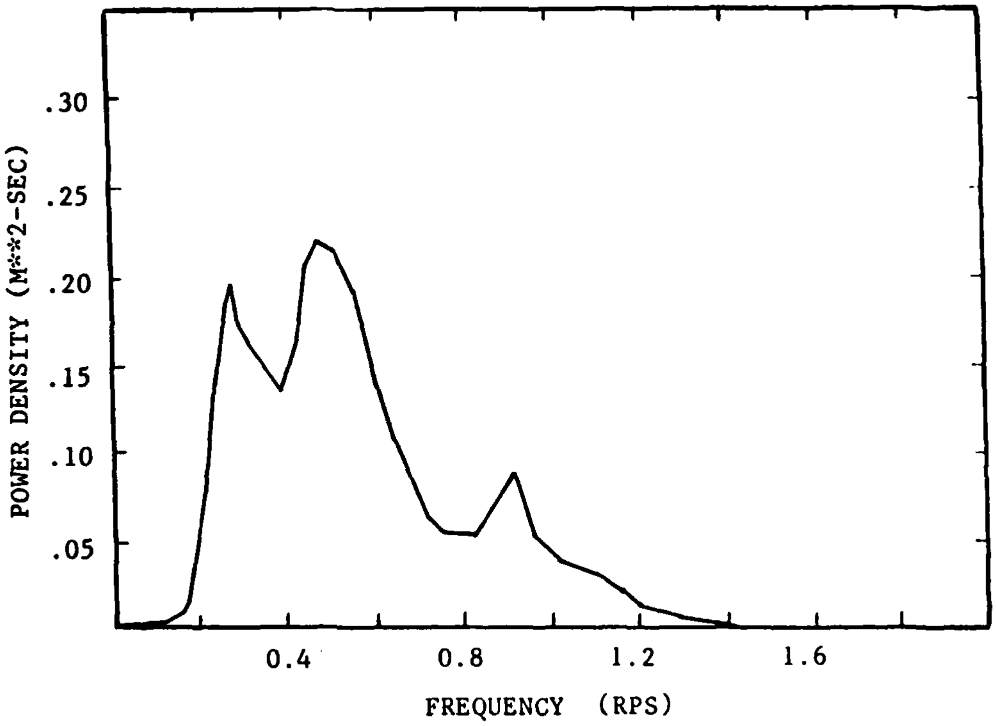
North Probe

Sea State 3 H

Sig. DA: 1.35 M

Amp. Max.: .248

Freq Max.: .497



Run No.: 1600 : 390.0 - 3800.0

Wave Height Spectrum

Stage 1

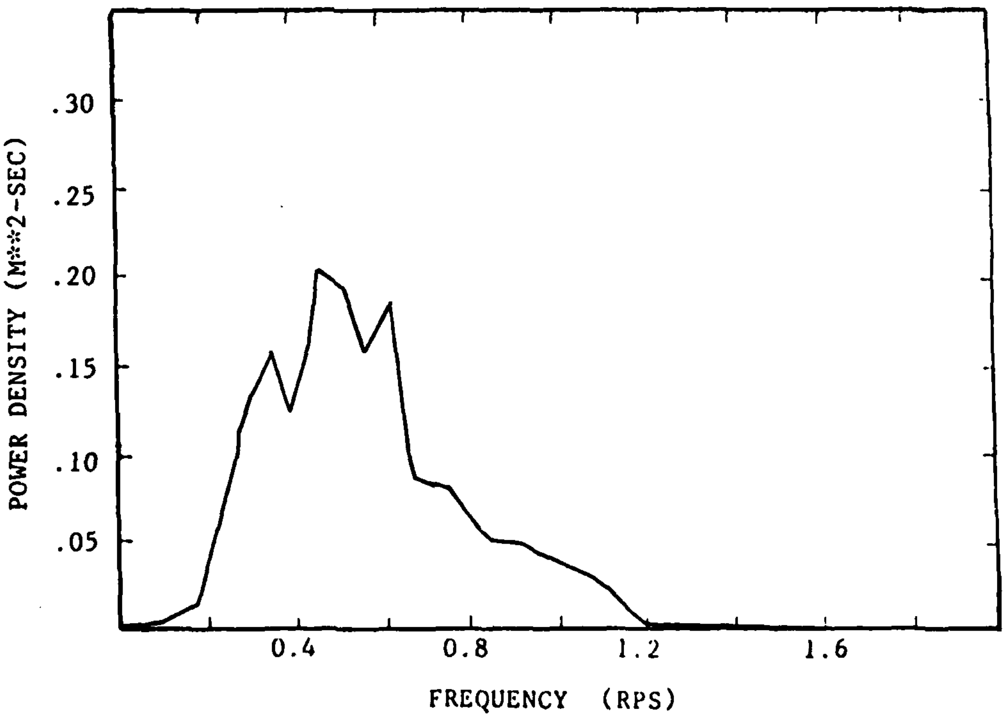
West Probe

Sea State 3 H

Sig. DA: 1.32 M

Amp. Max.: .201

Freq. Max.: .460



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 1600 : 380.0 - 3800.0

Wave Height Spectrum

Stage 1

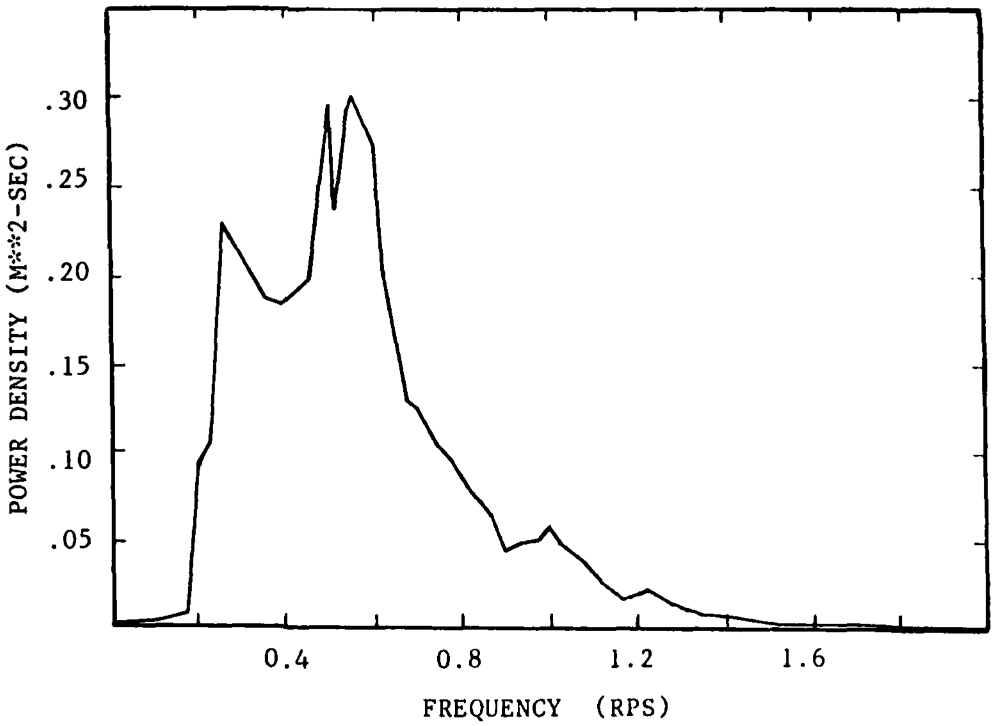
South Probe

Sea State 4 L

Sig. DA: 1.58 M

Amp. Max.: .302

Freq Max.: .567



Run No.: 1600 : 380.0 - 3800.0

Wave Height Spectrum

Stage 1

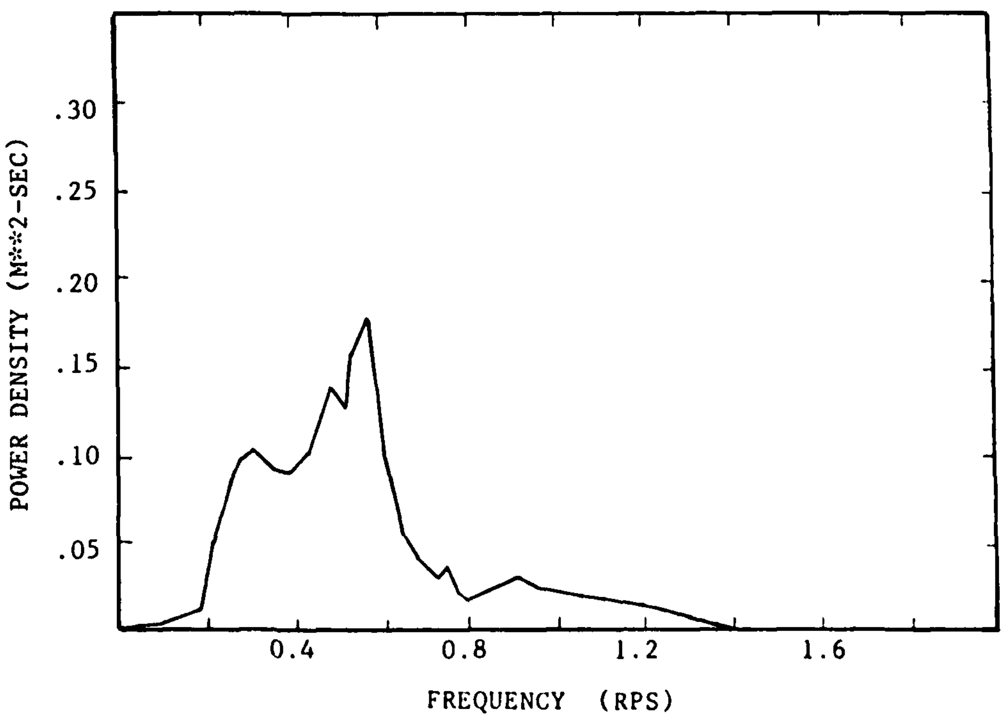
East Probe

Sea State 3 L

Sig. DA: 1.11 M

Amp. Max.: .171

Freq. Max.: .567



Run No.: 1 : 2000.0 - 6000.0

Wave Height Spectrum

Stage 2

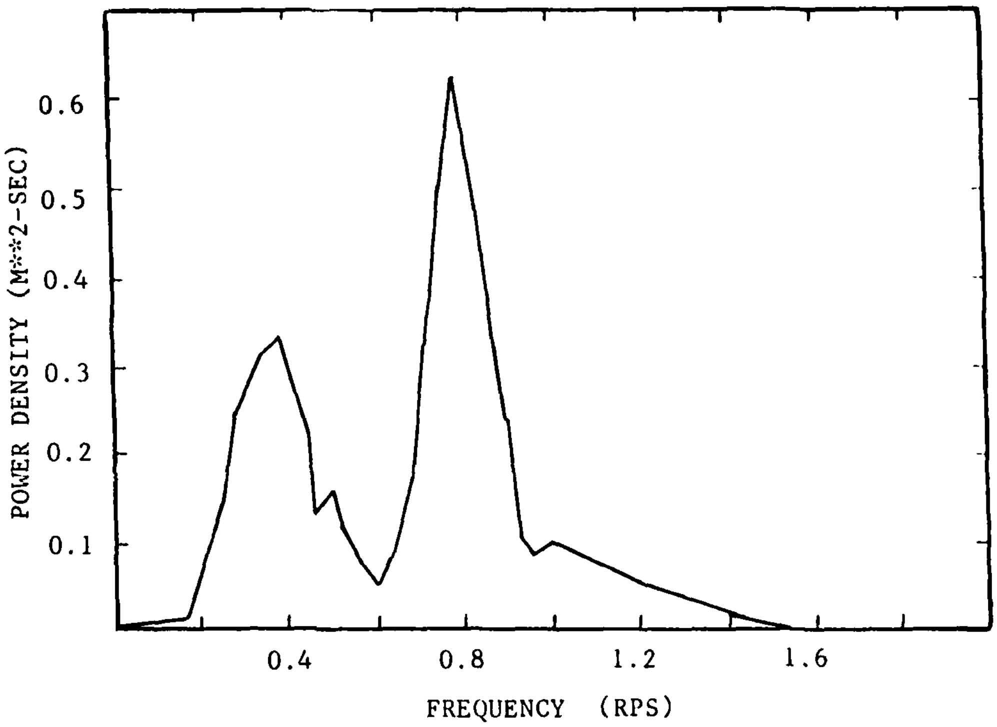
North Probe

Sea State 4 M

Sig. DA: 1.90 M

Amp. Max.: .635

Freq Max.: .780



Run No.: 1 : 2000.0 - 6000.0

Wave Height Spectrum

Stage 2

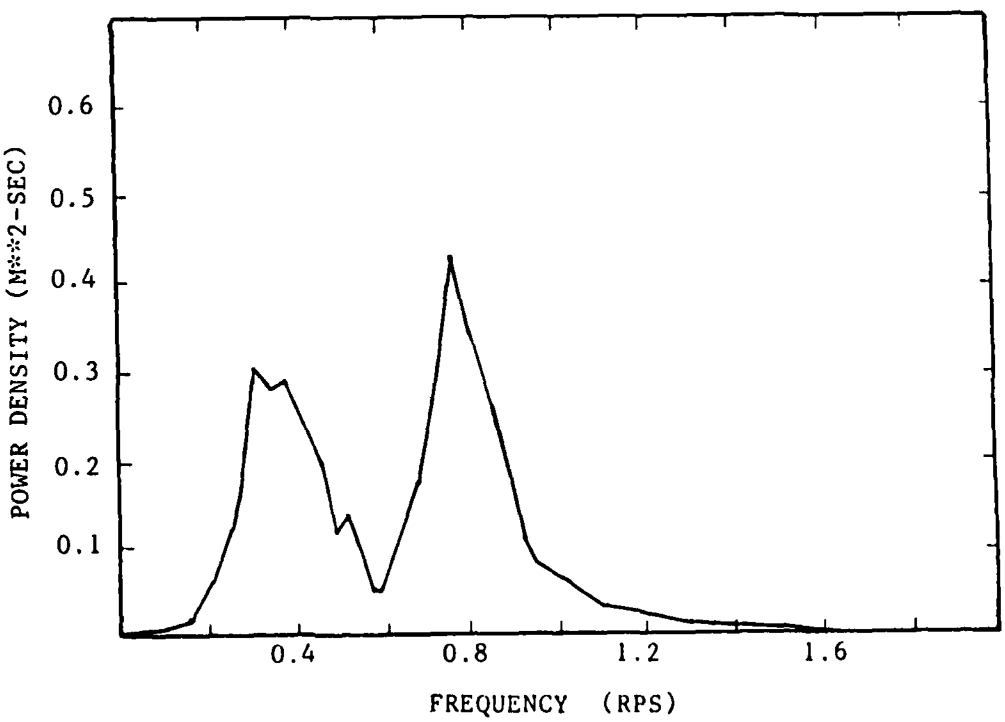
West Probe

Sea State 4 L

Sig. DA: 1.72 M

Amp. Max.: .438

Freq. Max.: .780



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 1 : 2000.0 - 6000.0

Wave Height Spectrum

Stage 2

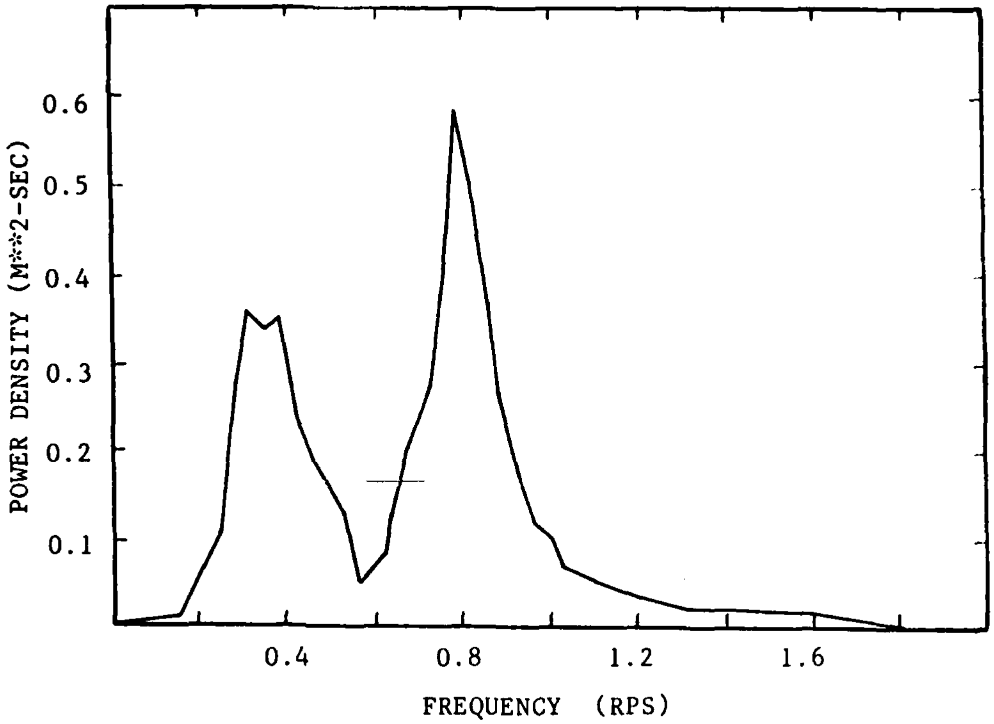
East WH Probe

Sea State 4 M

Sig. DA: 1.94 M

Amp. Max.: .590

Freq Max.: .780



Run No.: 21600 : 0.0 - 6000.0

Wave Height Spectrum

Stage 1

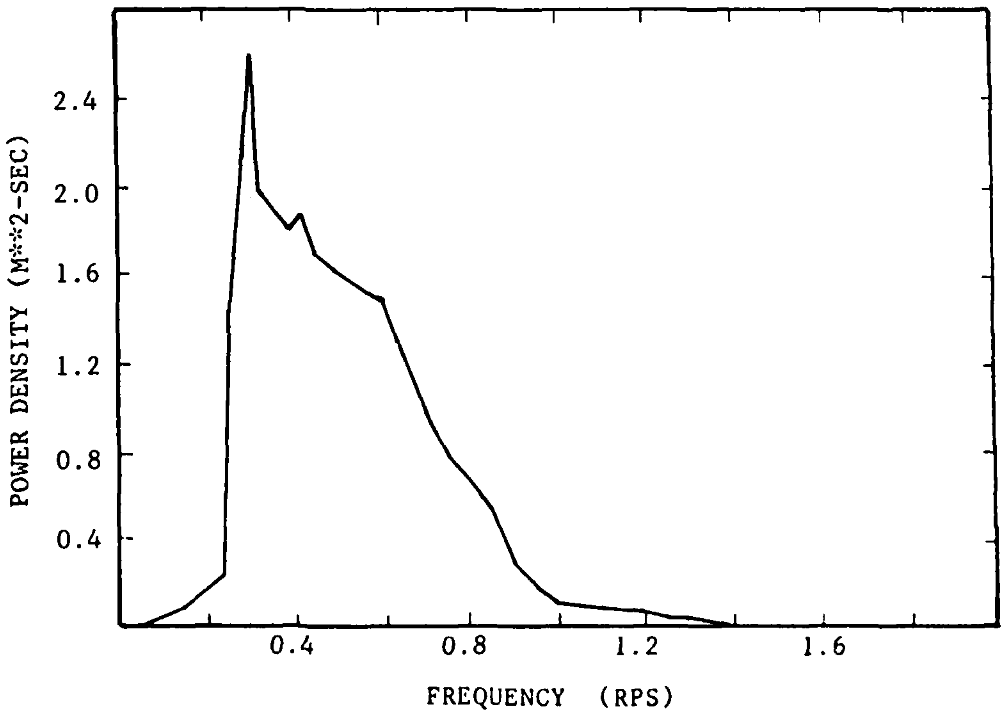
North Probe

Sea State 6 L

Sig. DA: 4.06 M

Amp. Max.: 2.648

Freq. Max.: .284



Run No.: 21600 : 0.0 - 6000.0

Wave Height Spectrum

Stage 1

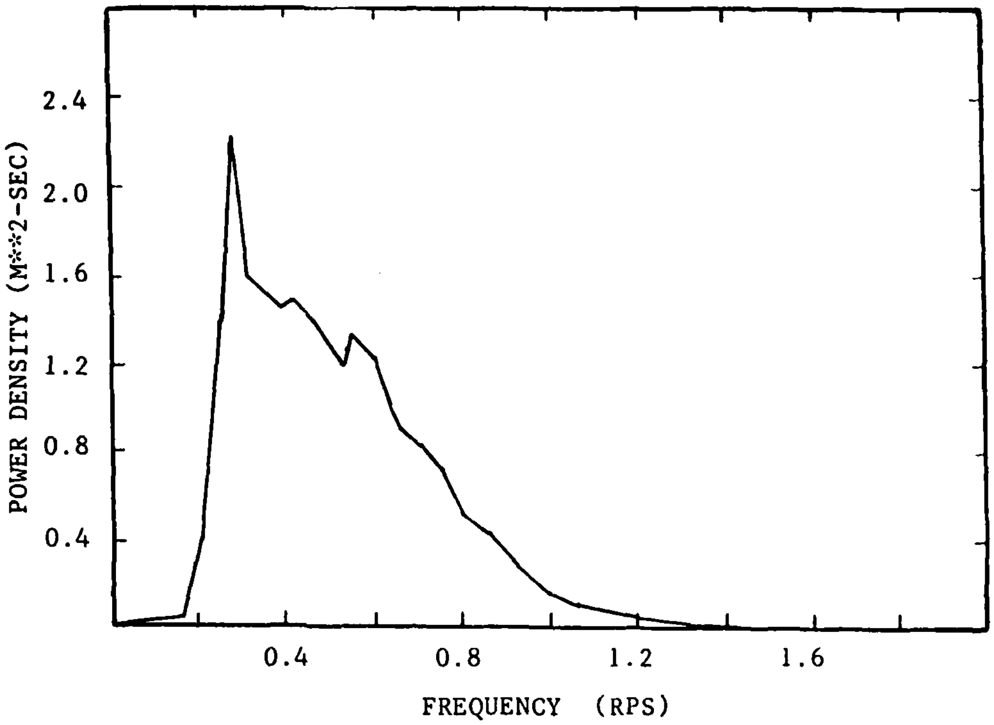
West Probe

Sea State 5 H

Sig. DA: 3.77 M

Amp. Max.: 2.24

Freq Max.: .284



Run No.: 21600 : 0.0 - 6000.0

Wave Height Spectrum

Stage 1

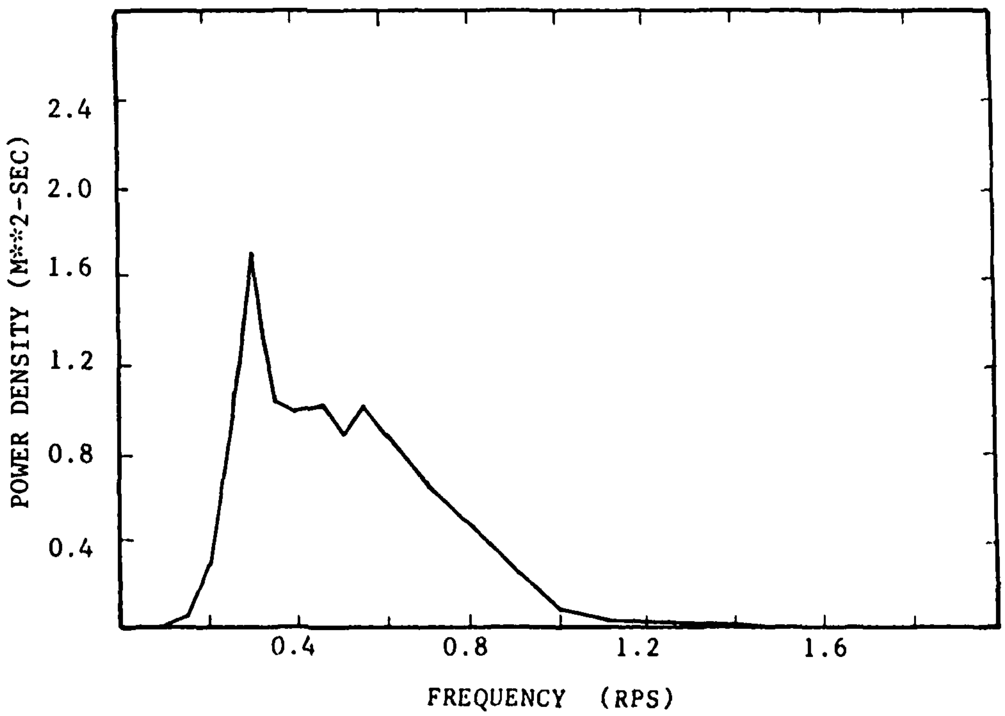
South Probe

Sea State 5 H

Sig. DA: 3.22

Amp. Max.: 1.755

Freq. Max.: .284



Run No.: 21600 : 0.0 - 6000.0

<u>Wave Height Spectrum</u>

Stage 1

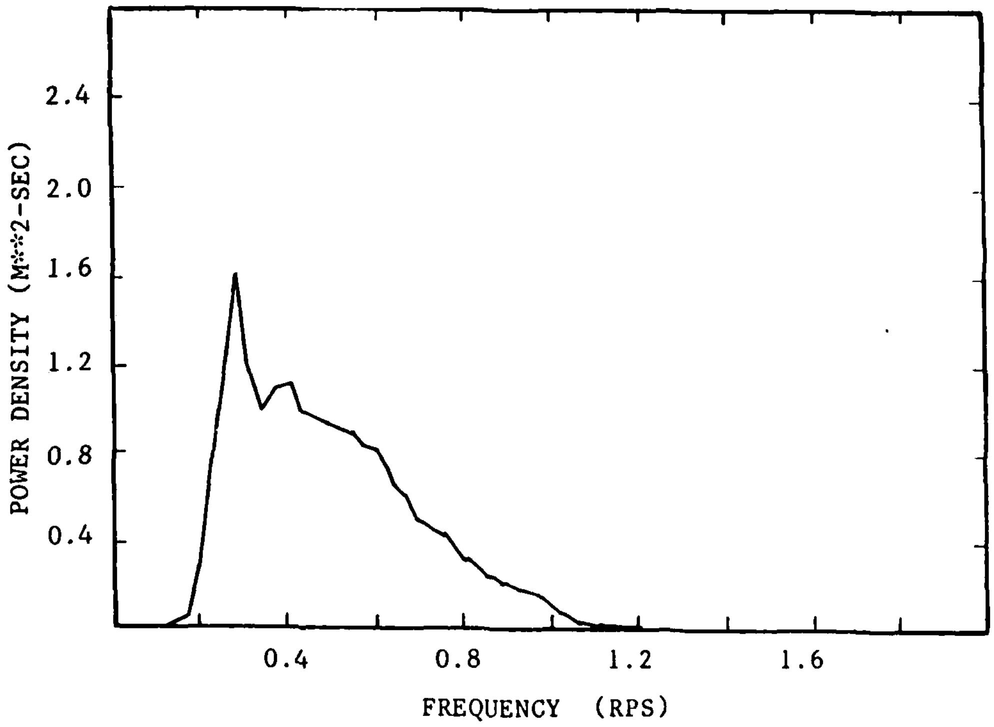
East Probe

Sea State 5 H

Sig. DA: 3.14 M

Amp. Max.: 1.651

Freq Max.: .284



Run No.: 21600 : 6001.0 - 14175.0

<u>Wave Height Spectrum</u>

Stage 2

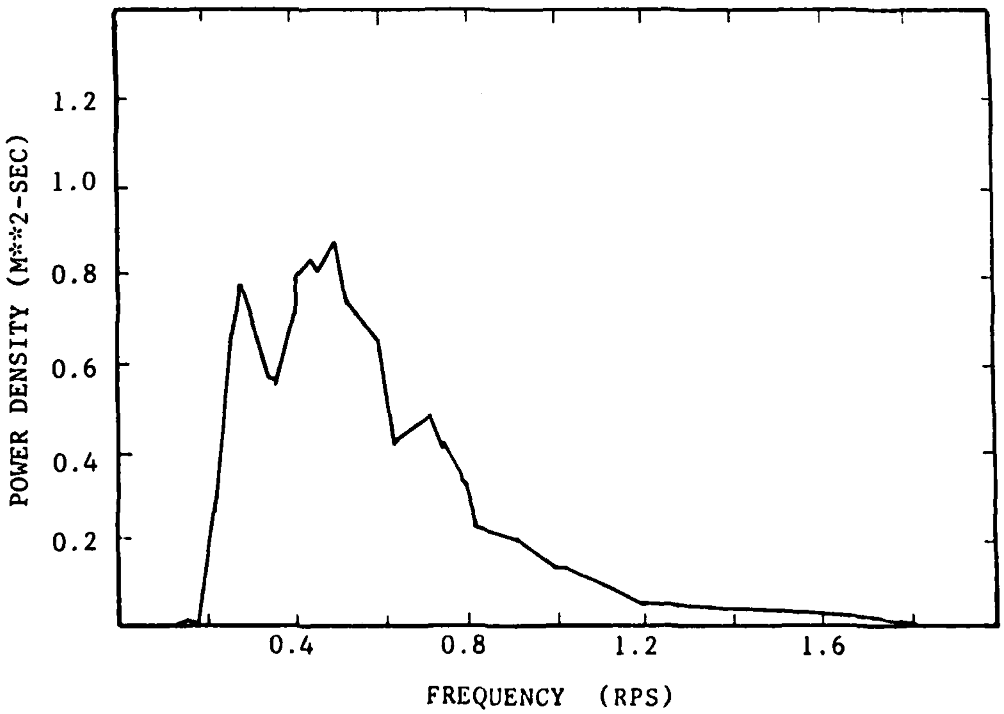
West Probe

Sea State 5 L

Sig. DA: 2.71 M

Amp. Max.: .898

Freq. Max.: .497



Run No.: 21600 : 6001.0 - 14175.0

<u>Wave Height Spectrum</u>

Stage 2

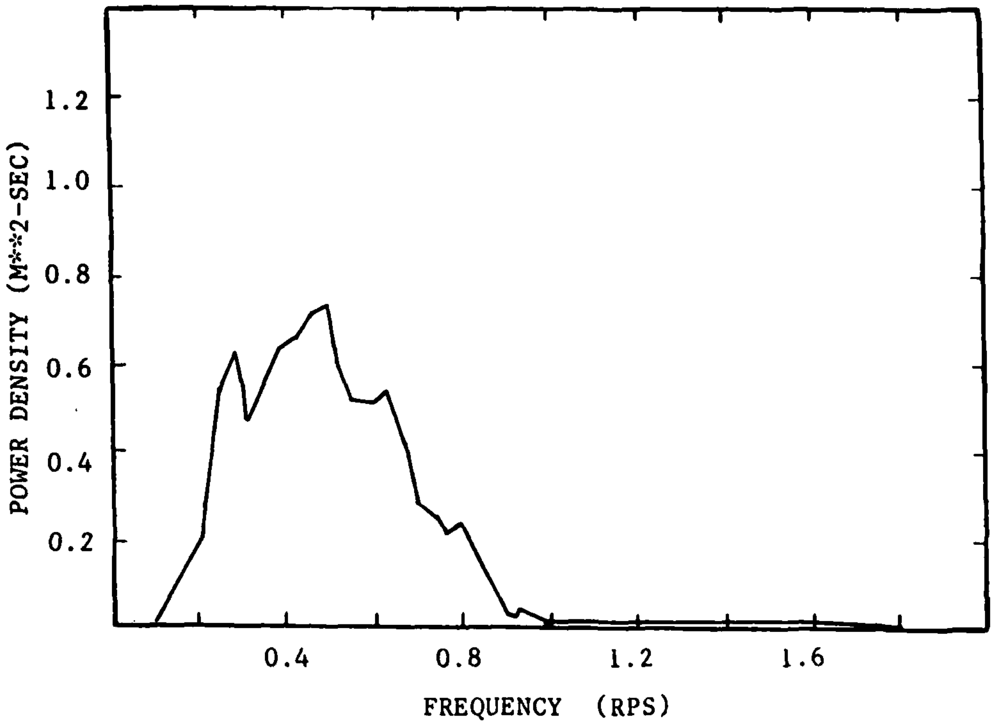
South Probe

Sea State 5 L

Sig. DA: 2.49 M

Amp. Max.: .746

Freq Max.: .497



Run No.: 21600 : 6001.0 - 14175.0

<u>Wave Height Spectrum</u>

Stage 2

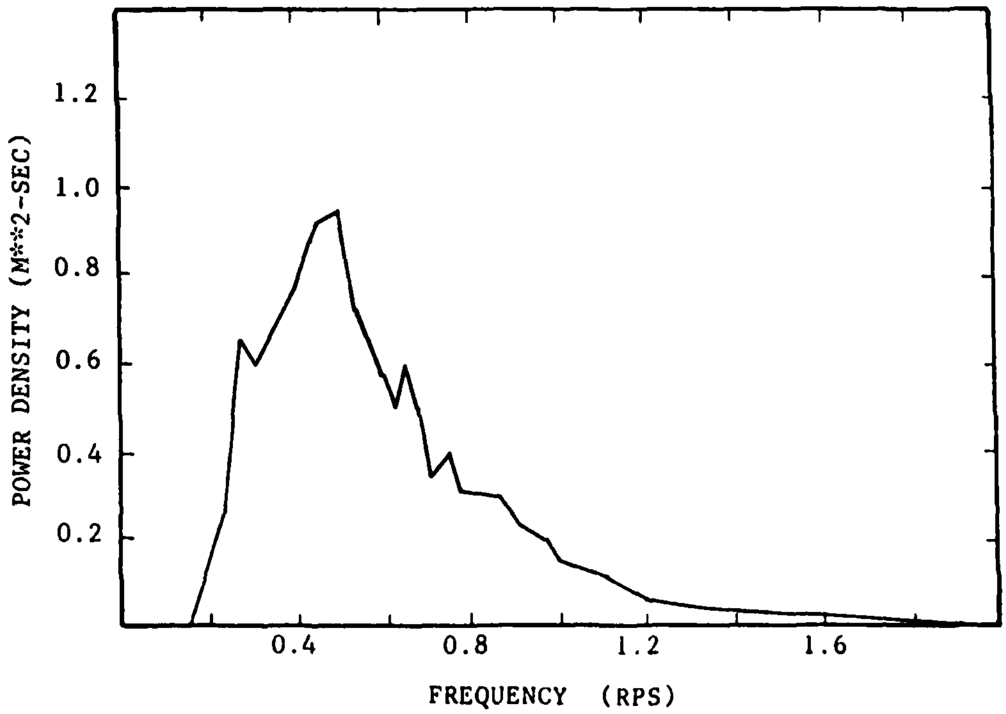
East Probe

Sea State 5 L

Sig. DA: 2.78

Amp. Max.: 9.70

Freq. Max.: .497



Run No.: 11900 : 1956.0 - 3756.0

Wave Height Spectrum

Stage 2

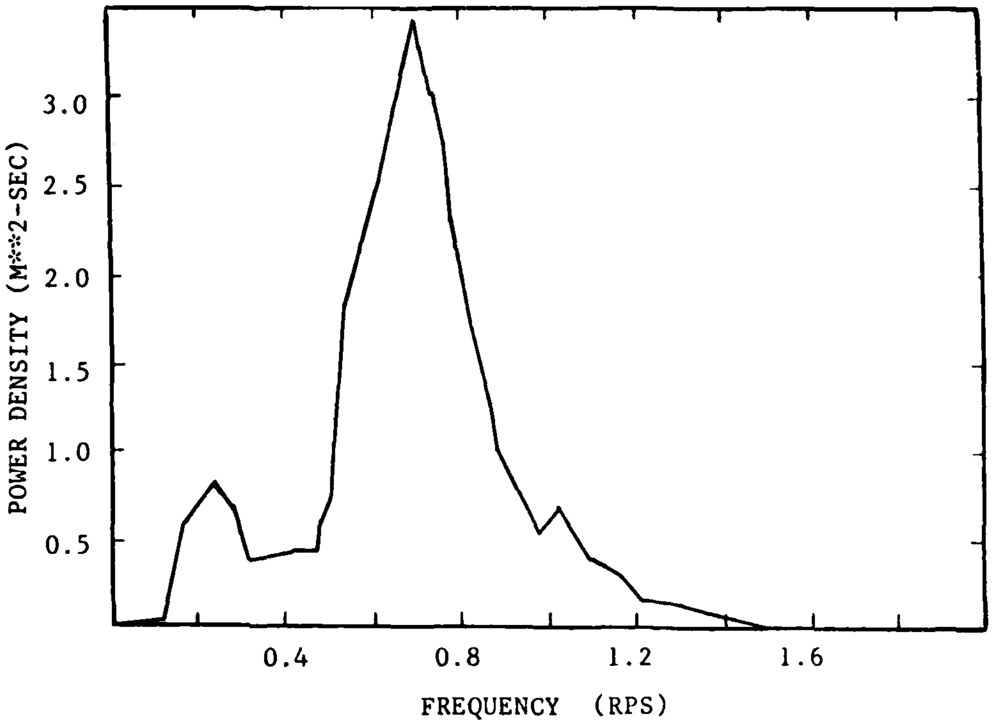
West Probe

Sea State 6 M

Sig. DA: 4.75 M

Amp. Max.: 3.468

Freq Max.: .674



Run No.: 11900 : 1956.0 - 3756.0

Wave Height Spectrum

Stage 2

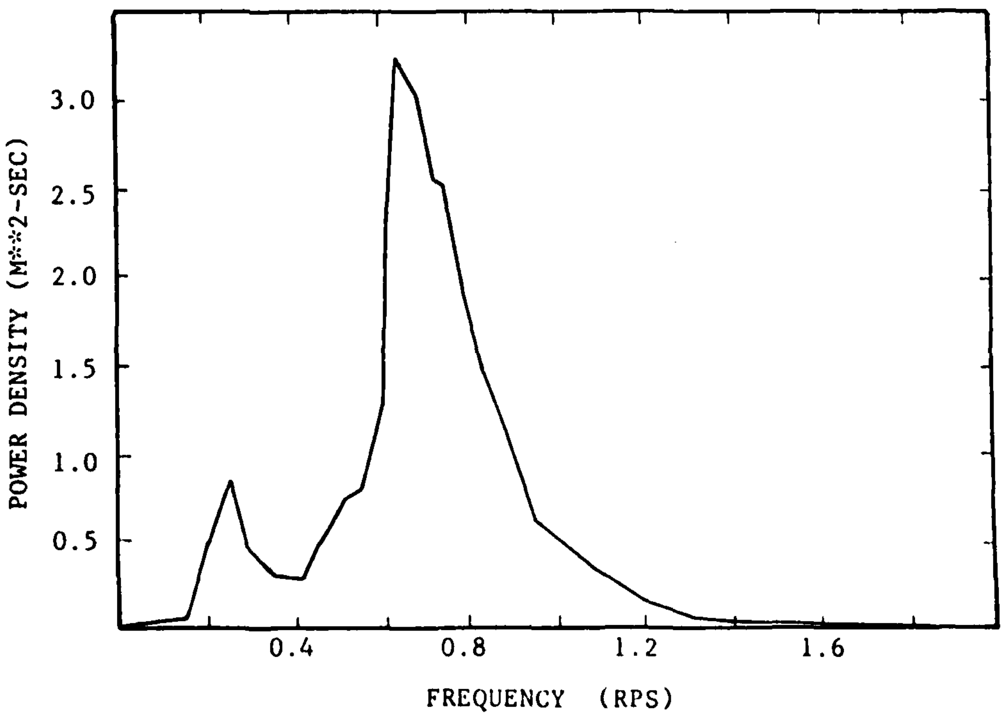
South Probe

Sea State 6 M

Sig. DA: 4.50 M

Amp. Max.: 3.259

Freq. Max.: .638



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 11900 : 1956.0 - 3756.0

Wave Height Spectrum

Stage 2

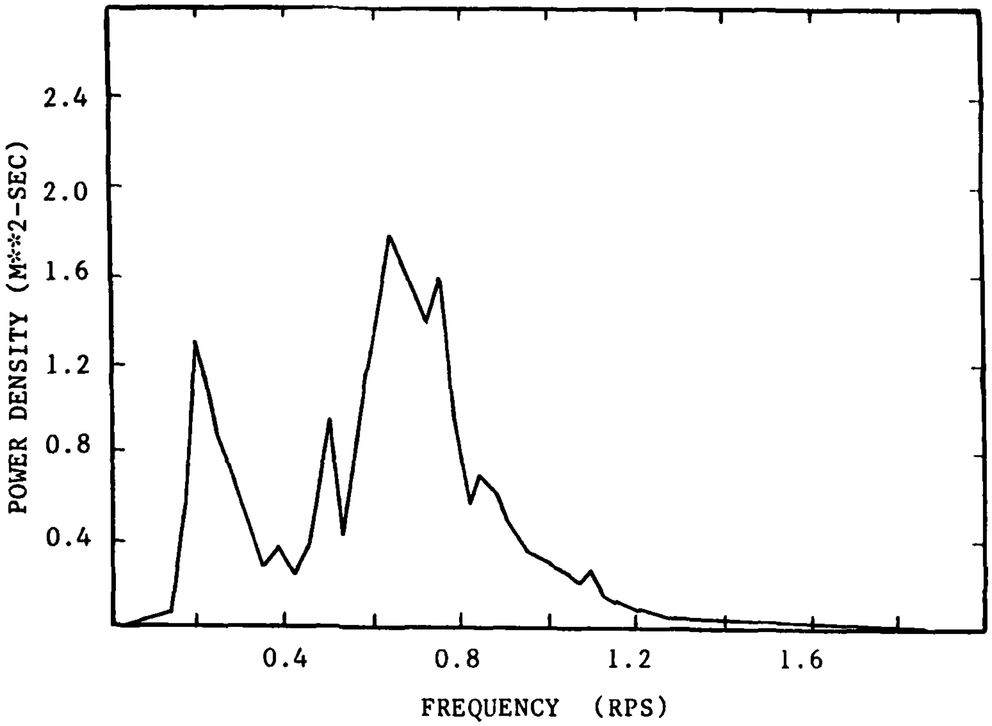
East Probe

Sea State 5 H

Sig. DA: 3.55 M

Amp. Max.: 1.845

Freq Max.: .638



Run No.: 4100 : 69.0 - 1854.0

Wave Height Spectrum

Stage 2

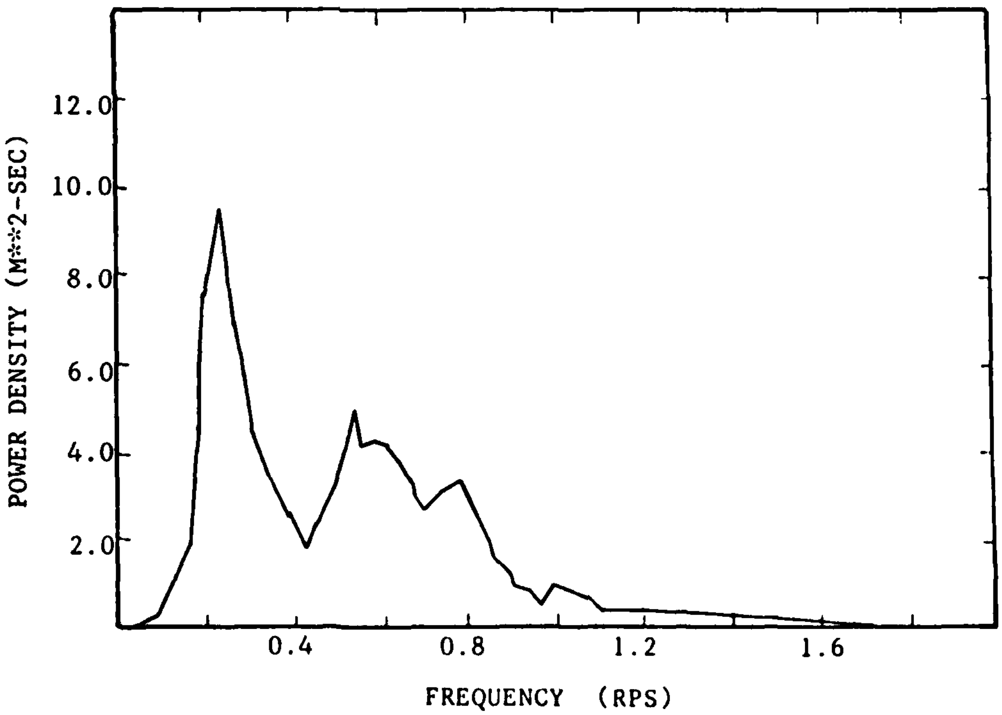
North Probe

Sea State 7 L

Sig. DA: 7.27 M

Amp. Max.: 9.441

Freq. Max.: .213



Run No.: 4100 : 69.0 - 1854.0

Wave Height Spectrum

Stage 2

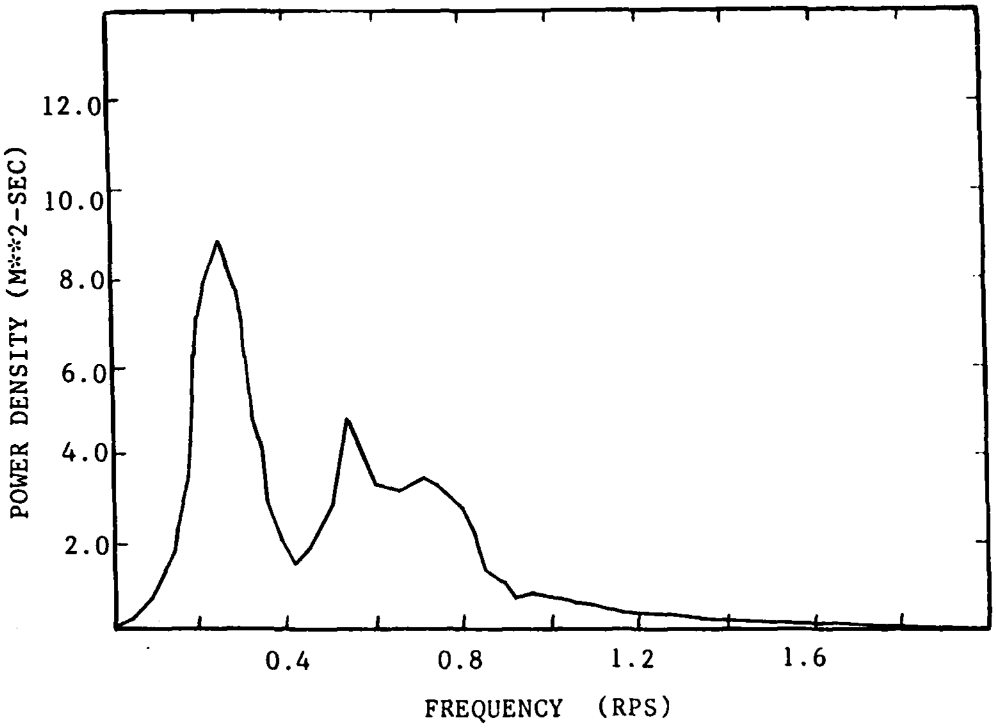
West Probe

Sea State 7 L

Sig. DA: 7.05 M

Amp. Max.: 8.812

Freq Max.: .248



Run No.: 4100 : 69.0 - 1854.0

Wave Height Spectrum

Stage 2

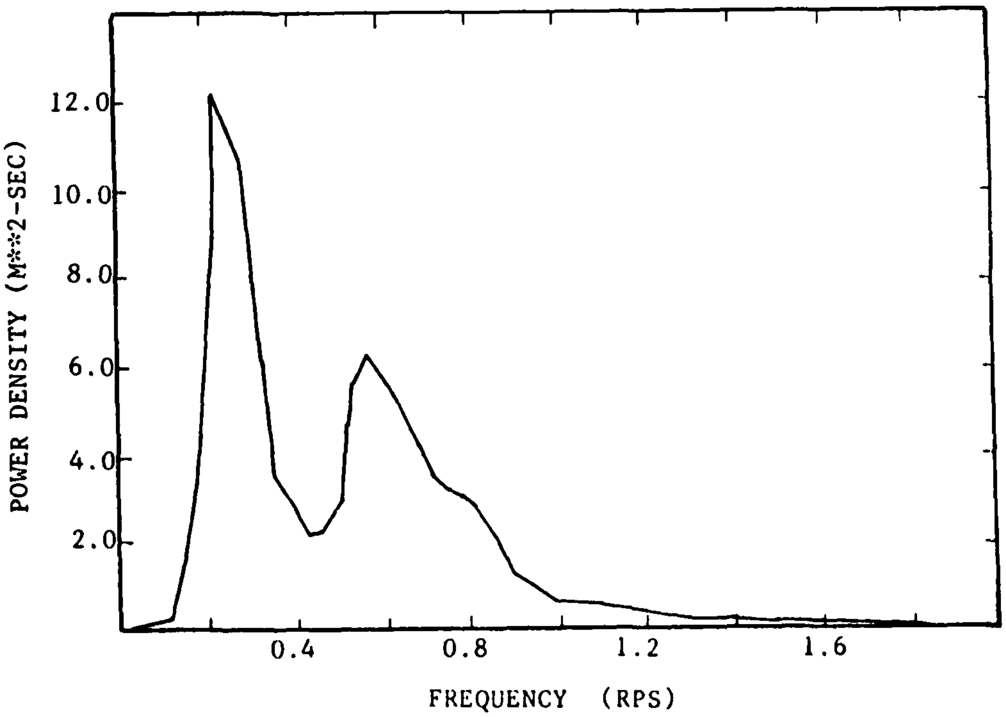
South Probe

Sea State 7 M

Sig. DA: 8.15 M

Amp. Max.: 12.222

Freq. Max.: .248



Run No.: 4100 : 69.0 - 1854.0

Wave Height Spectrum

Stage 2

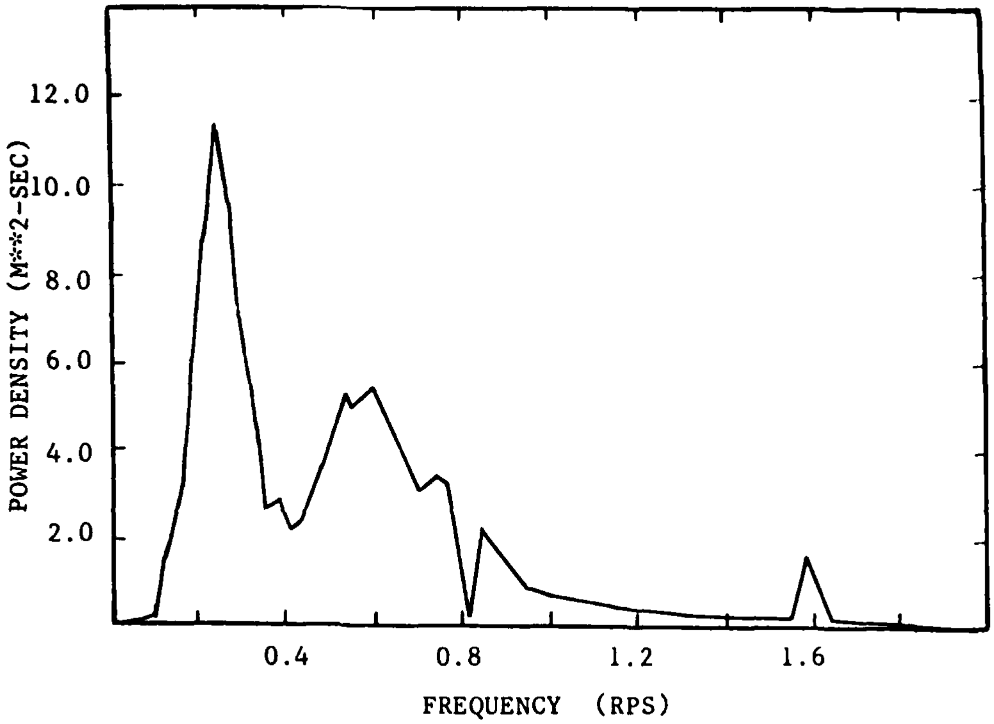
East Probe

Sea State 7 M

Sig. DA: 7.97 M

Amp. Max.: 11.380

Freq Max.: .248



Run No.: 4900 : 3761.0 - 5155.0

Wave Height Spectrum

Stage 1

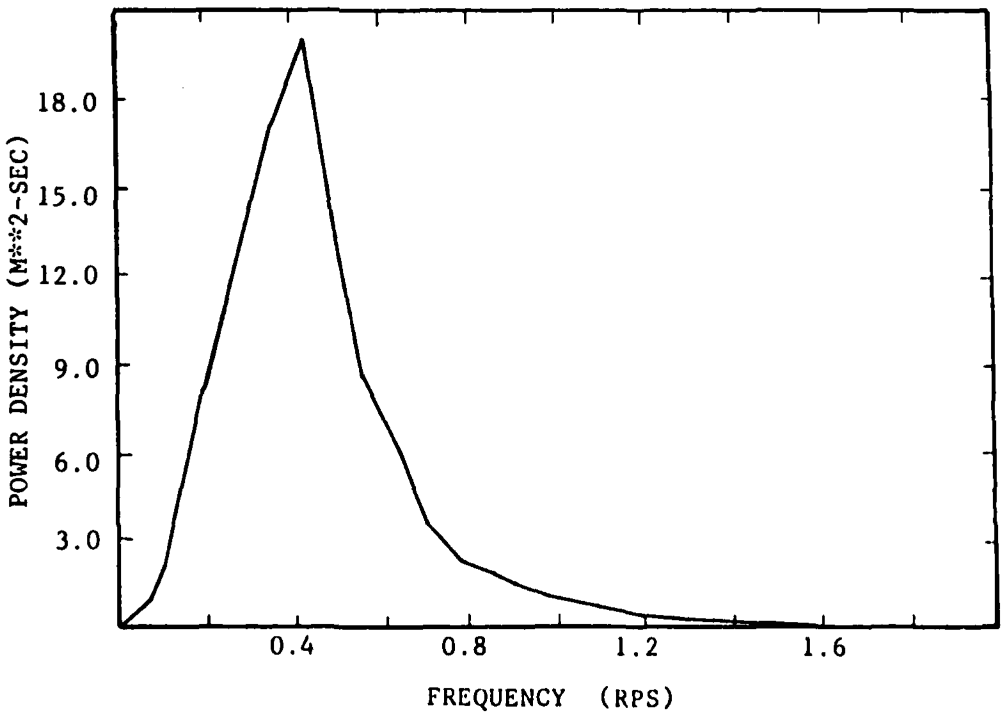
North Probe

Sea State 7 H

Sig. DA: 10.0 M

Amp. Max.: 20.217

Freq. Max.: .426



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 4900 : 3761.0 - 5155.0

Wave Height Spectrum

Stage 1

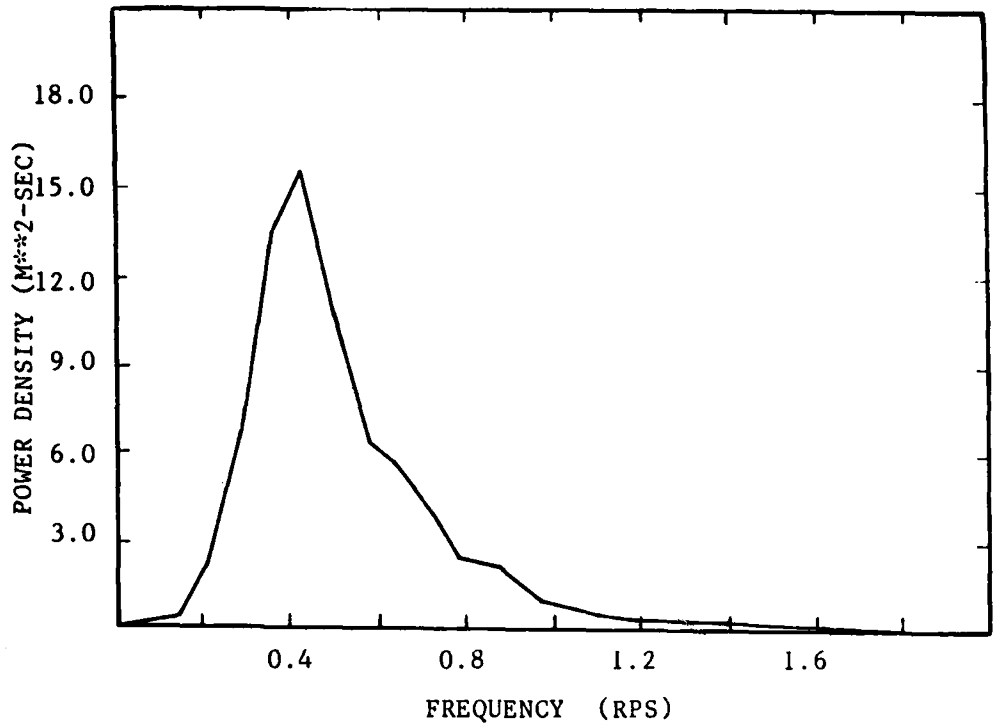
West Probe

Sea State 7H

Sig. DA: 9.14 M

Amp. Max.: 15.092

Freq Max.: .426



Run No.: 4900 : 3761.0 - 5155.0

Wave Height Spectrum

Stage 1

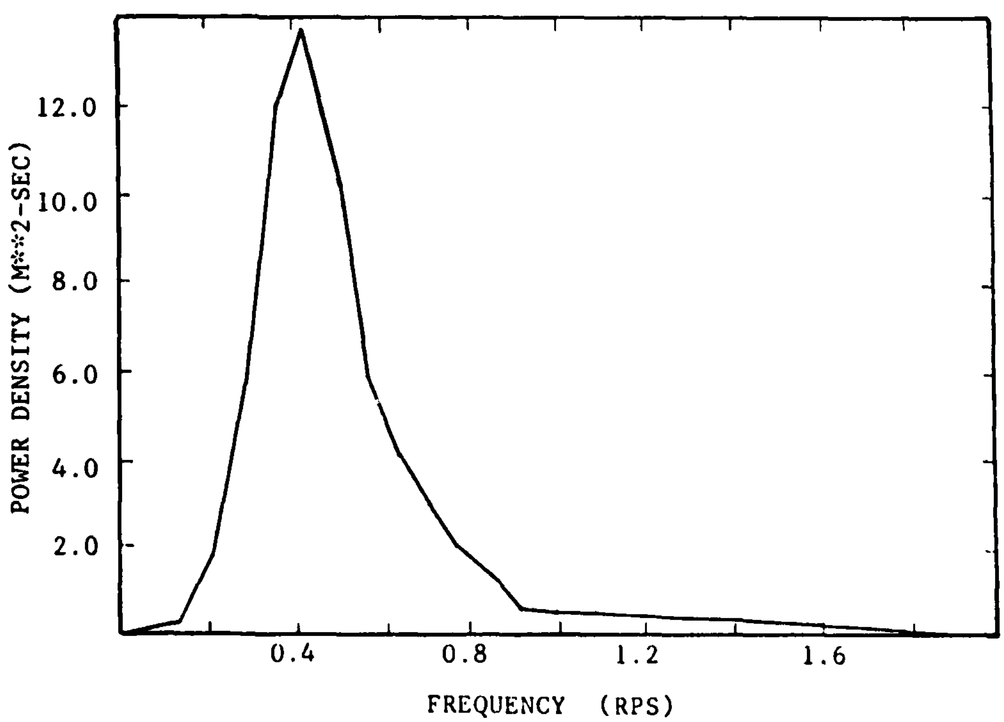
East Probe

Sea State 7 M

Sig. DA: 8.59 M

Amp. Max.: 13.291

Freq. Max.: .426



Run No.: 11700 : 6767.0 - 10367.0

Wave Height Spectrum

Stage 2

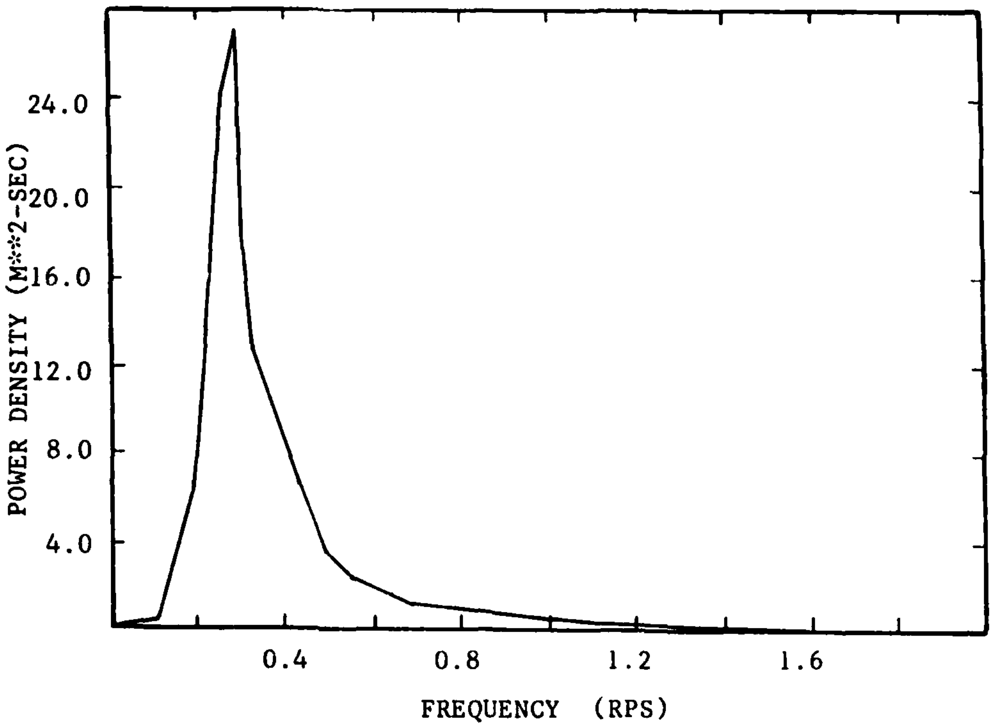
West Probe

Sea State 7 M

Sig. DA: 8.85 M

Amp. Max.: 27.264

Freq Max.: .284



Run No.: 11700 : 6767.0 - 10367.0

Wave Height Spectrum

Stage 2

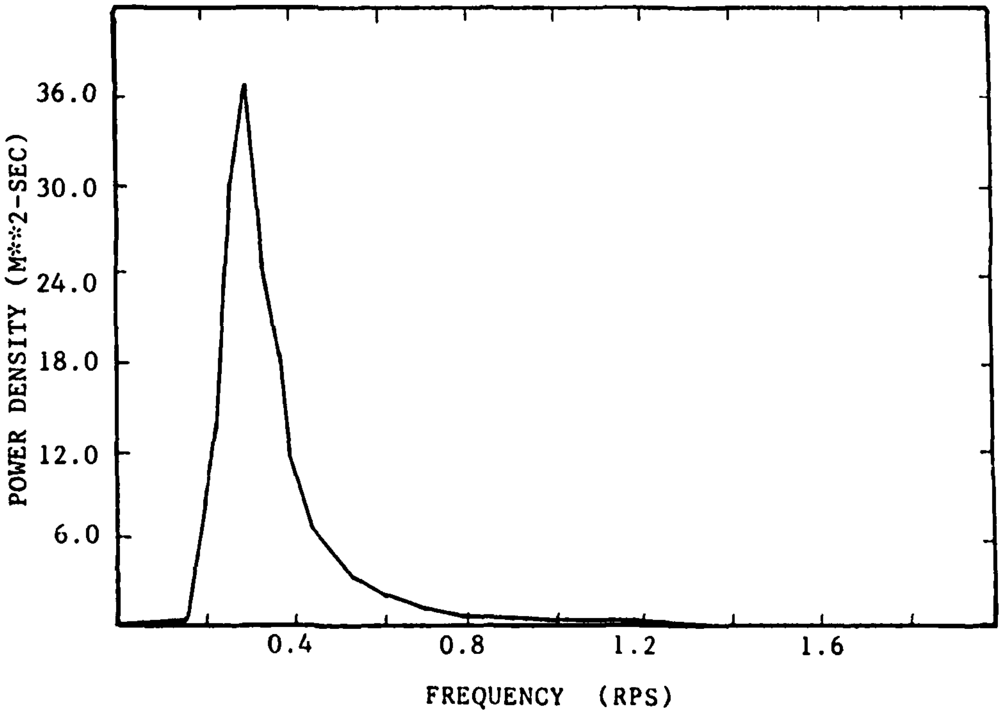
South Probe

Sea State 7 H

Sig. DA: 10.0 M

Amp. Max.: 36.413

Freq. Max.: .284



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 11700 : 6767.0 - 10367.0

Wave Height Spectrum

Stage 2

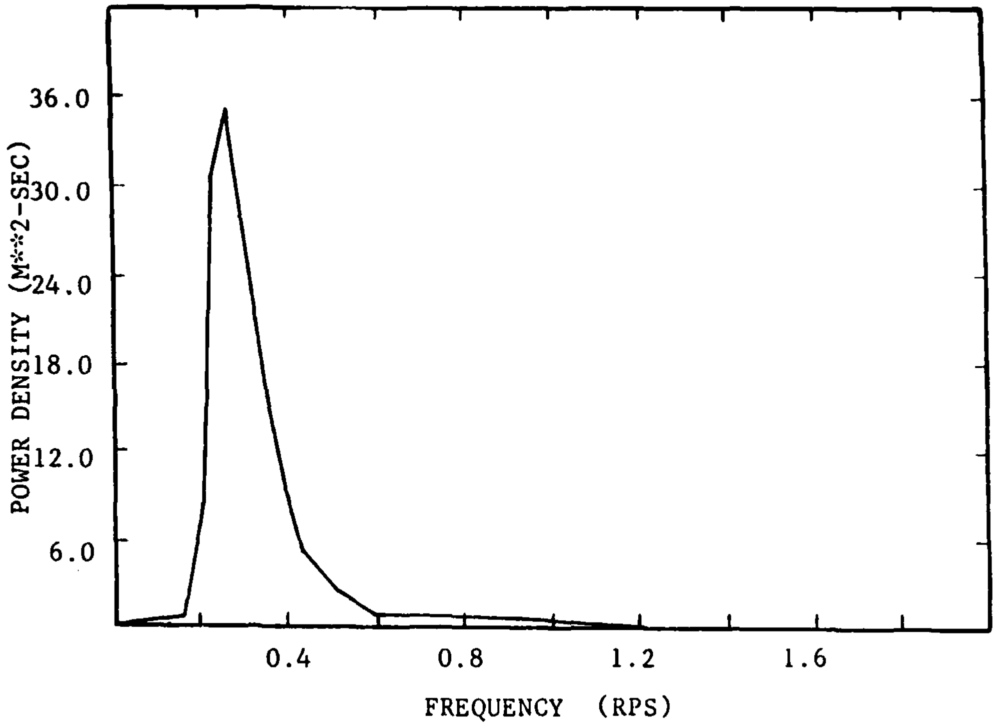
East Probe

Sea State 7 H

Sig. DA: 9.32 M

Amp. Max.: 35.946

Freq Max.: .284



Run No.: 3 : 0.0 - 7313.4

Wave Height Spectrum

Stage 1

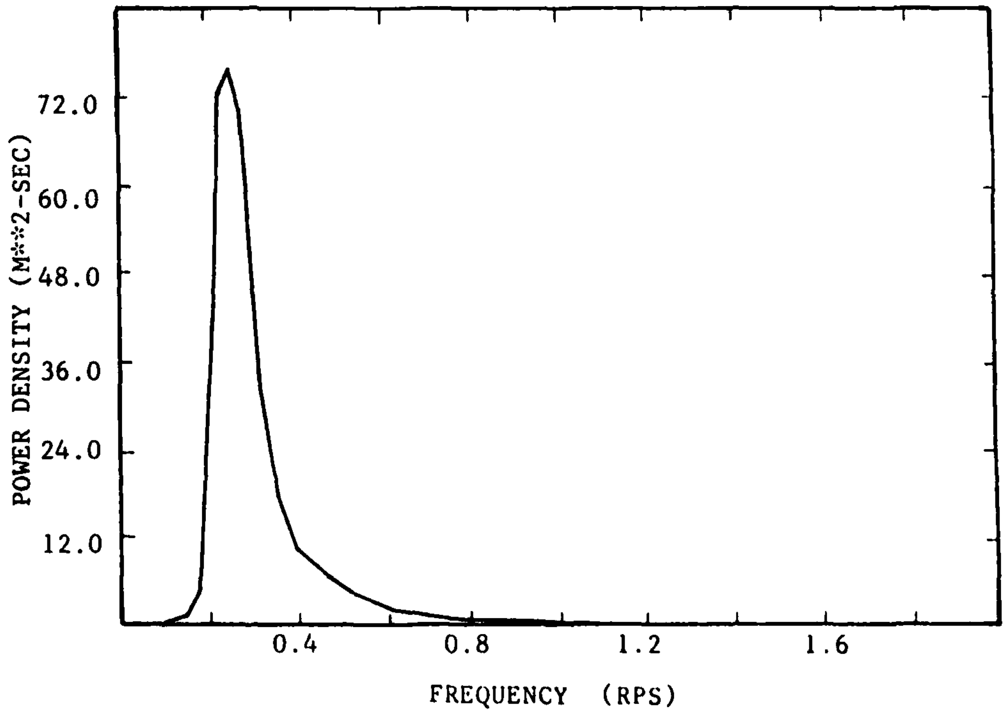
North Probe

Sea State 8 L

Sig. DA: 12.4 M

Amp. Max.: 74.511

Freq. Max.: .248



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 3 : 0.0 - 7313.4

Wave Height Spectrum

Stage 1

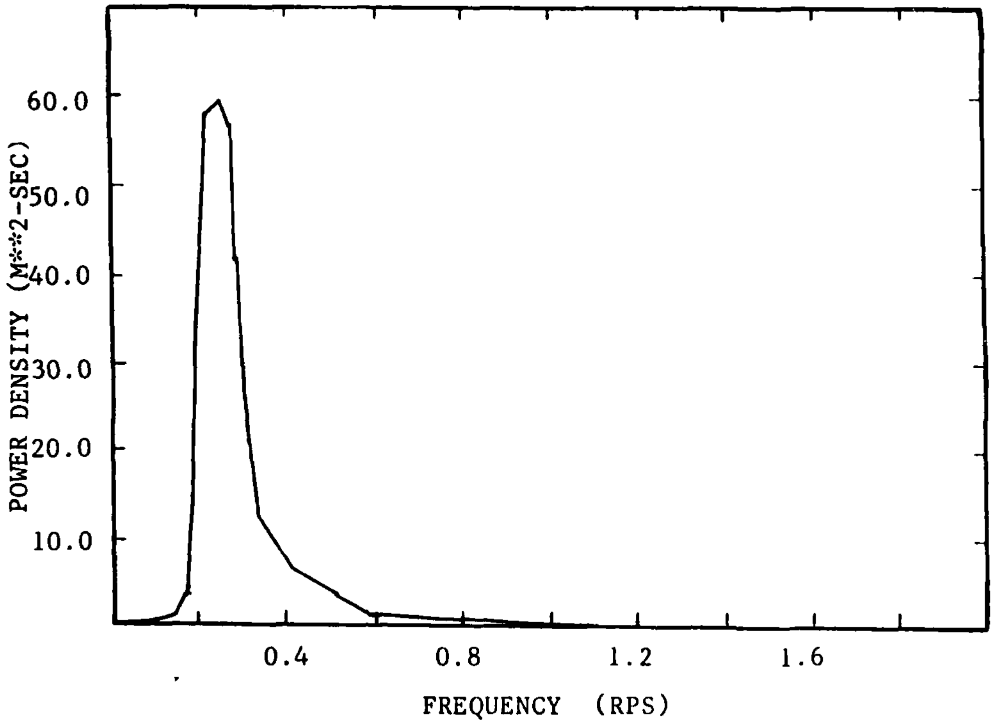
East Probe

Sea State 8 L

Sig. DA: 12.4 M

Amp. Max.: 57.946

Freq Max.: .248



Run No.: 3 : 0.0 - 7282.8

Wave Height Spectrum

Stage 1

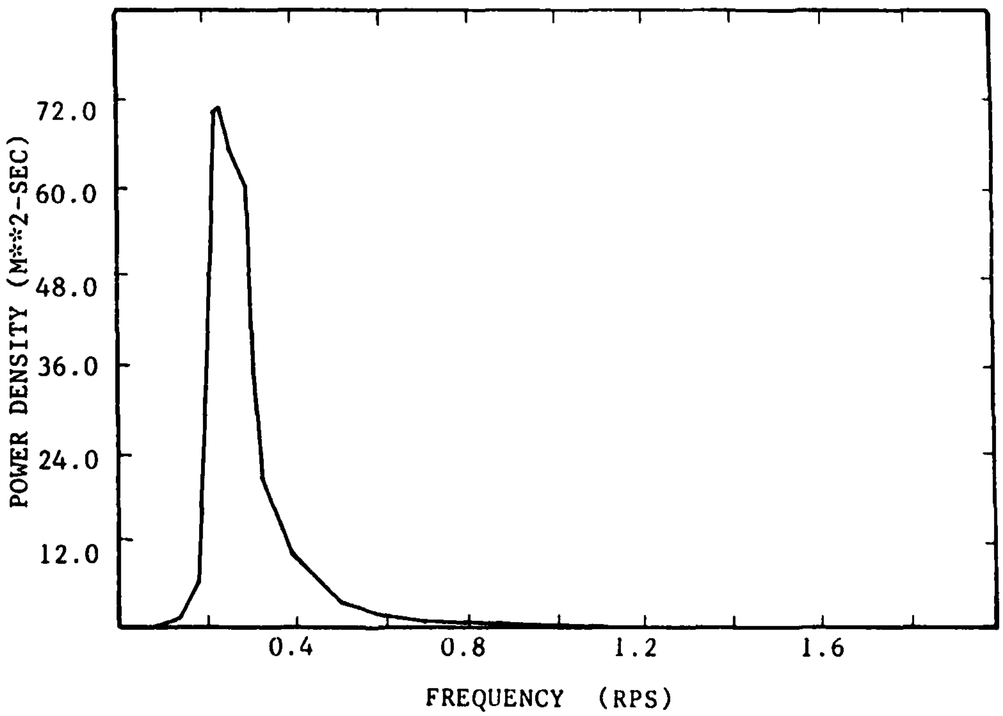
West Probe

Sea State 7 H

Sig. DA: 11.1 M

Amp. Max.: 71.503

Freq. Max.: .248



GULF OF MEXICO - ENVIRONMENTAL MEASURING SYSTEM

Run No.: 3 : 0.0 - 7282.8

Wave Height Spectrum

Stage 1

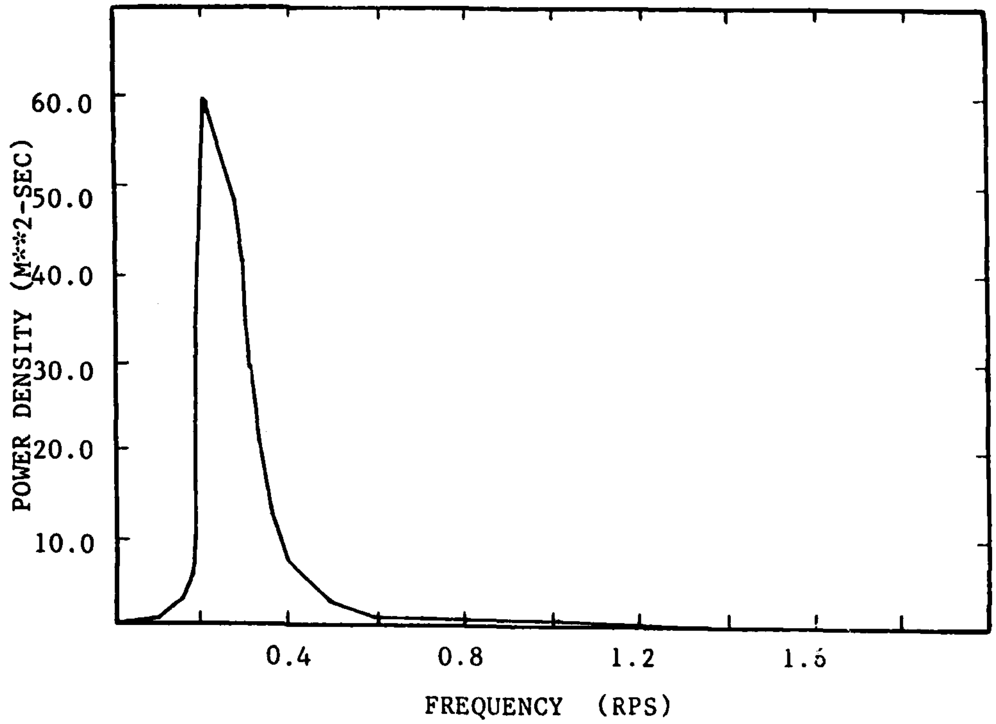
South Probe

Sea State 7 H

Sig. DA: 10.9 M

Amp. Max.: 59.007

Freq Max.: .231



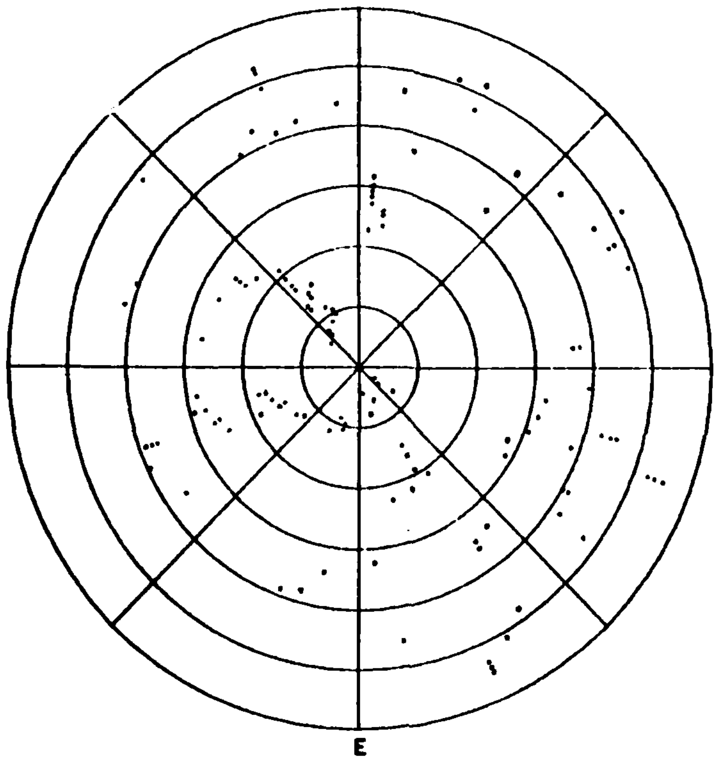
APPENDIX B

Gulf of Mexico Directional Wave Spectra

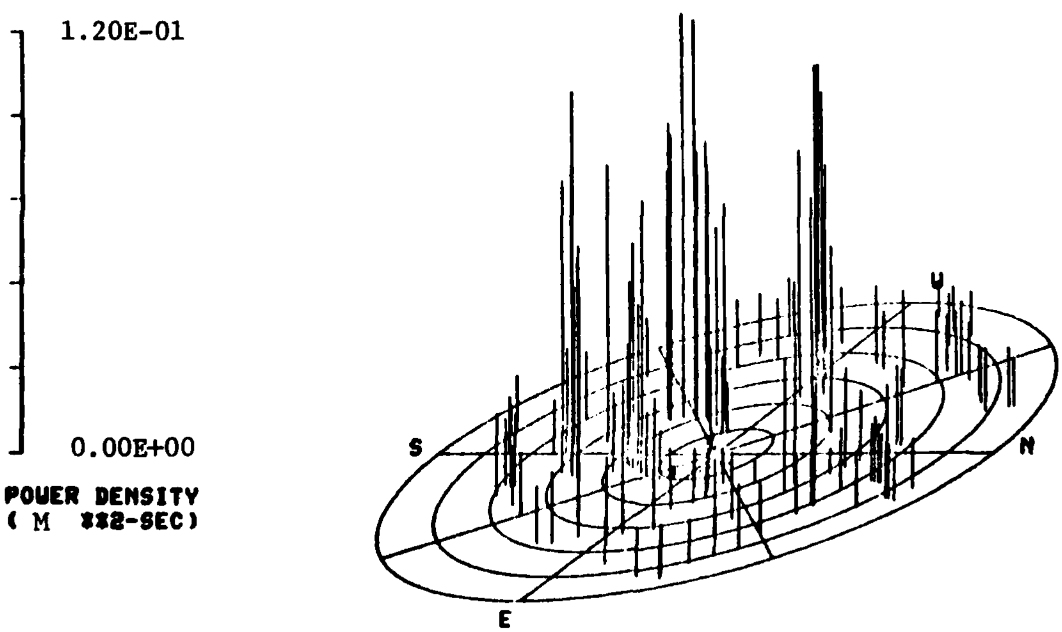
Direction is plotted radially on the polar plots. Frequency is plotted with zero at the polar center. The two-dimensional plots are top views of the three-dimensional plots. Power is plotted only on the three-dimensional directional spectrum plots. The base of the vector on three-dimensional directional spectrum plot intersects the polar plane at the direction and frequency of the power vector. The vector length indicates the amount of power from that frequency and direction. Arrows have been drawn on the two-dimensional directional spectrum plot to indicate the seaway direction judged to be predominant at that stage.

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 1600.: 380.0 - 3800.0 256 FREQUENCIES
TRANSDUCERS : 1 NORTH 1 WEST 1 SOUTH 1 EAST



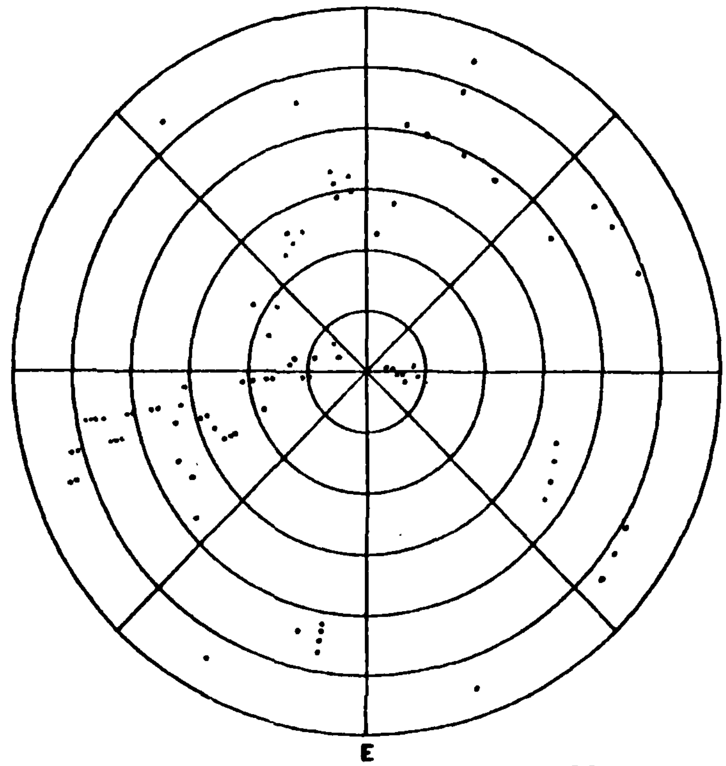
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



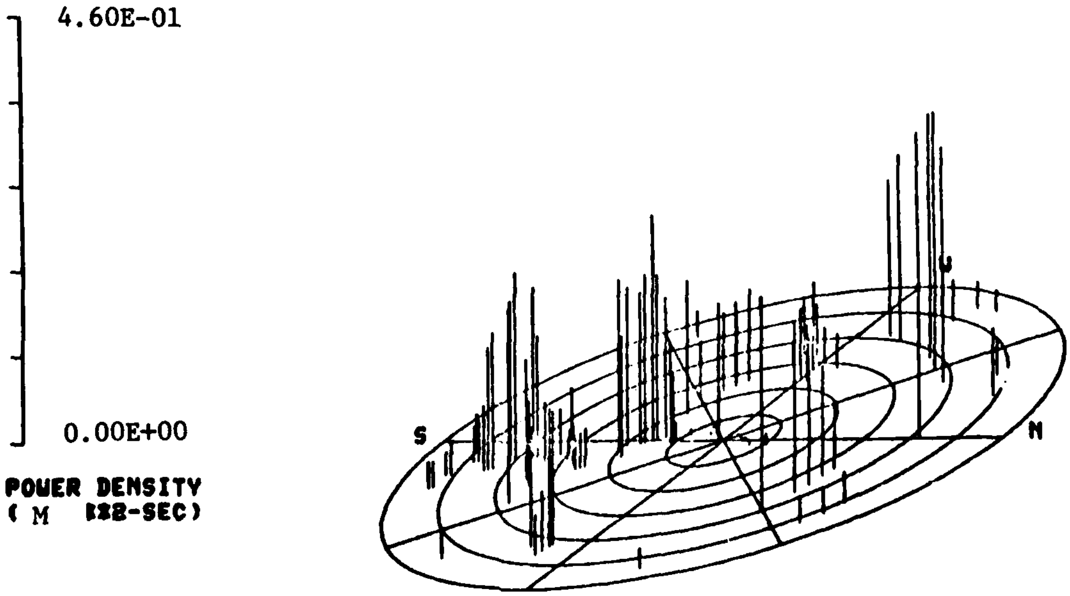
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 1.: 2000.0 - 6000.0 256 FREQUENCIES
TRANSDUCERS : 2NORTHWH 2WEST WH 2EAST WH



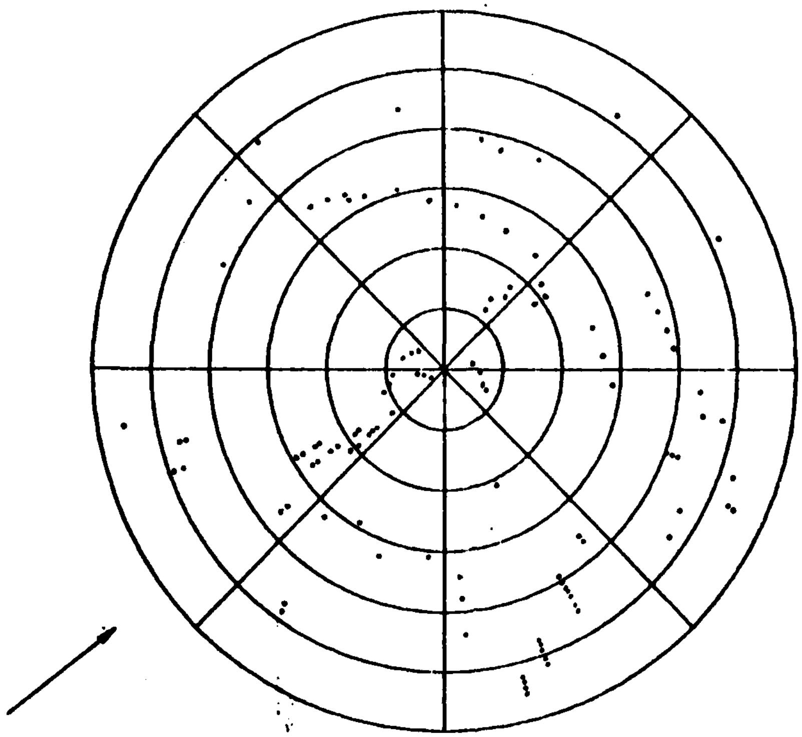
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



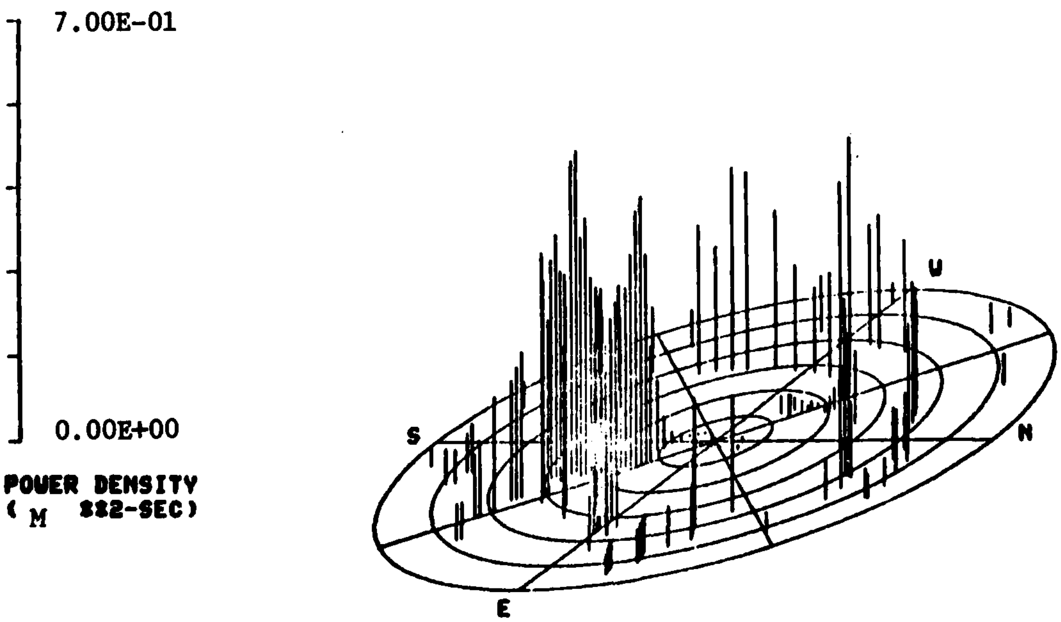
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 21600.: 0.0 - 6000.0 256 FREQUENCIES
TRANSDUCERS : 1 NORTH 1 WEST 1 SOUTH 1 EAST



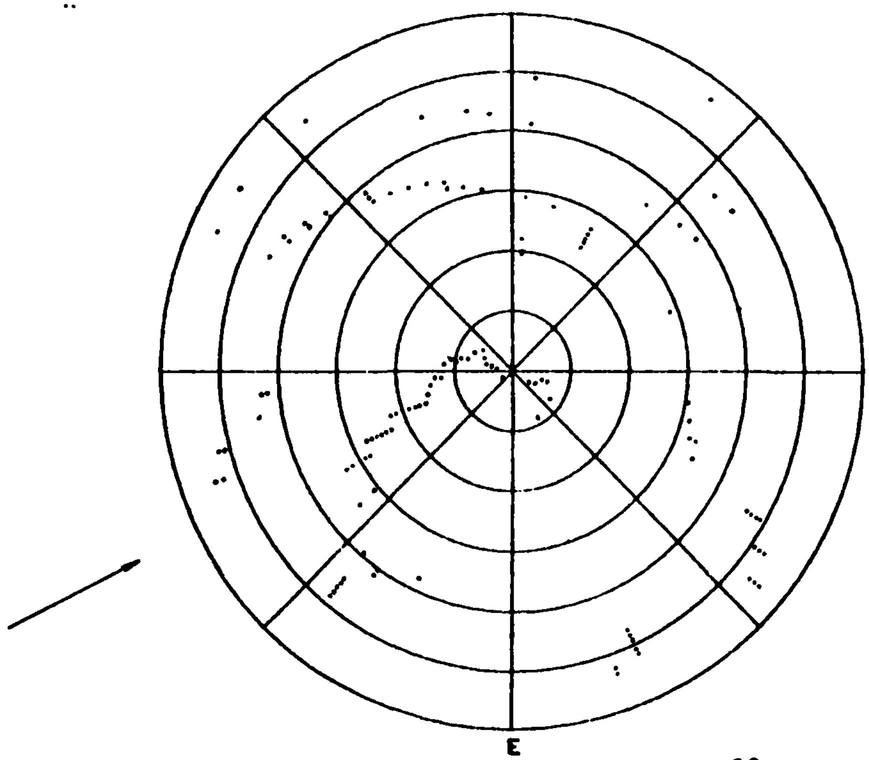
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



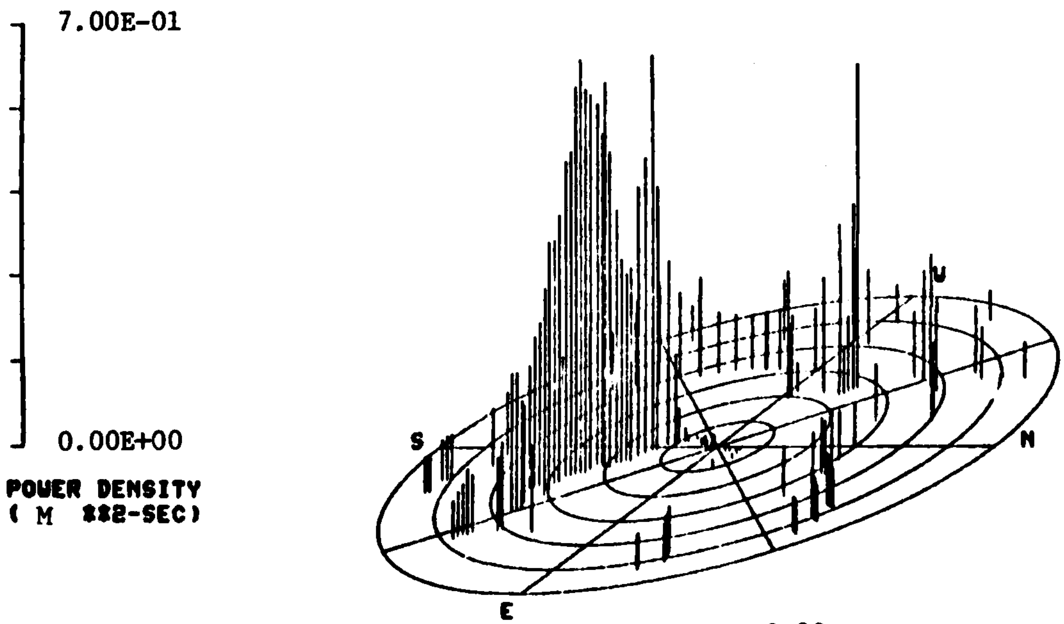
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 21600.: 6001.0 - 14175.0   256 FREQUENCIES
TRANSDUCERS : 2 WEST 2 SOUTH 2 EAST



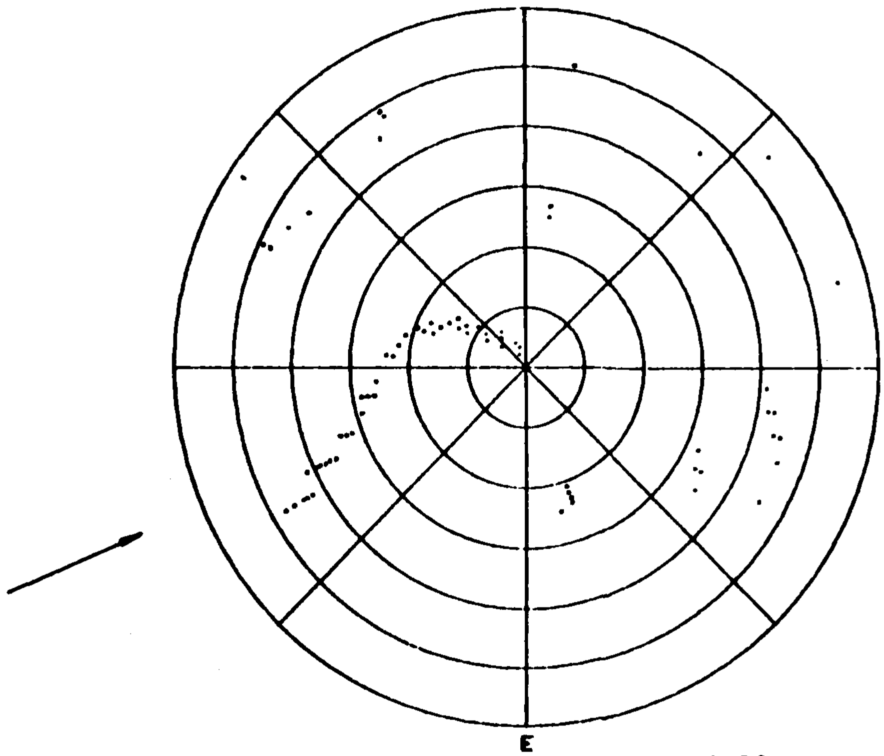
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



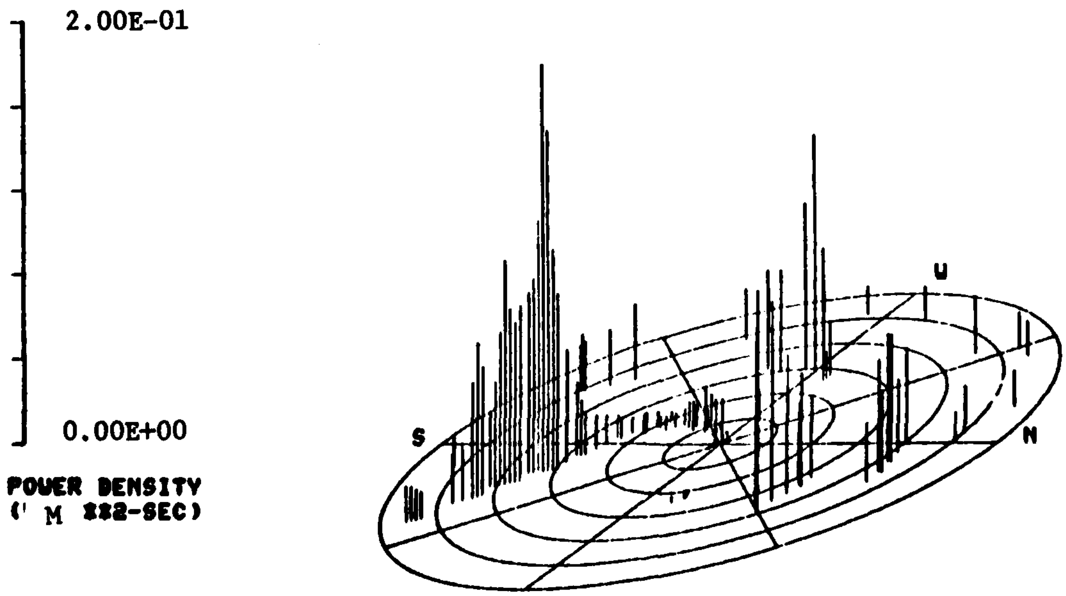
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 11900.: 1956.0 - 3756.0 256 FREQUENCIES
TRANSDUCERS : 2 WEST 2 SOUTH 2 EAST



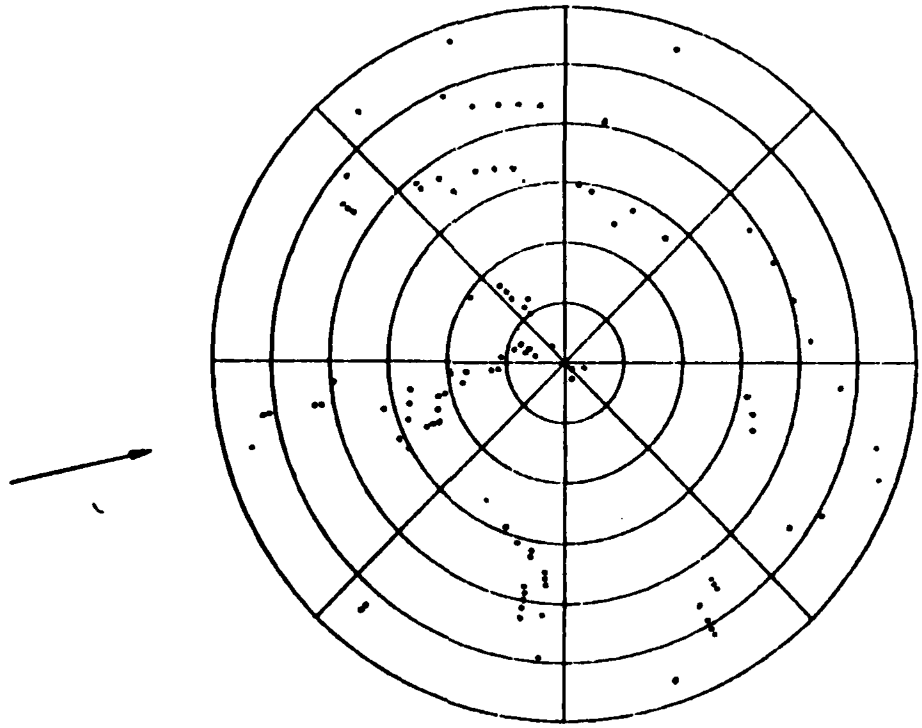
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



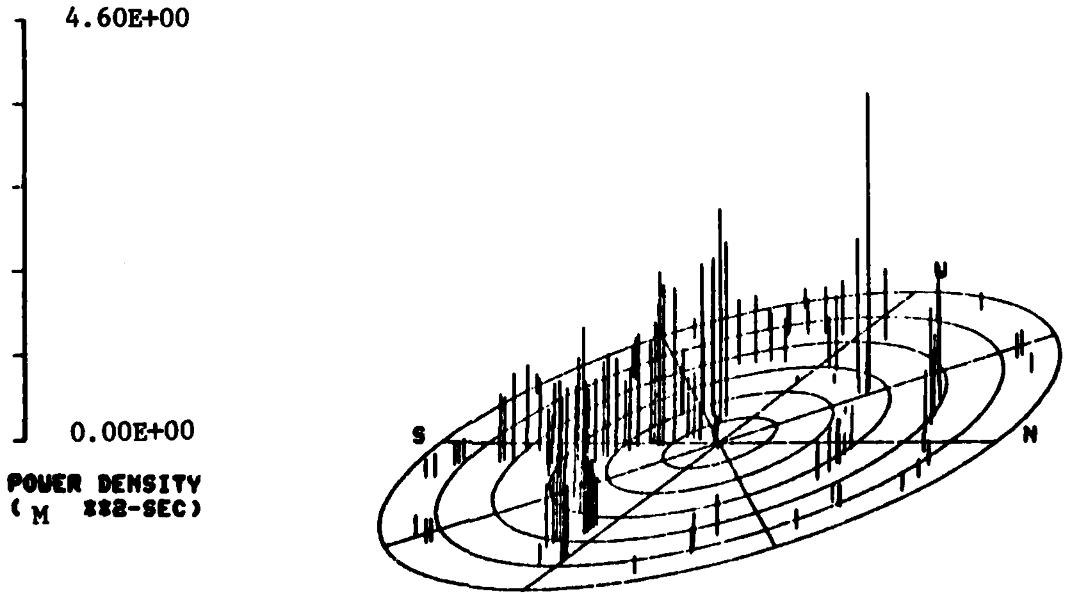
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 4100.: 69.0 - 1854.0 256 FREQUENCIES
TRANSDUCERS : 2 NORTH 2 WEST 2 SOUTH 2 EAST



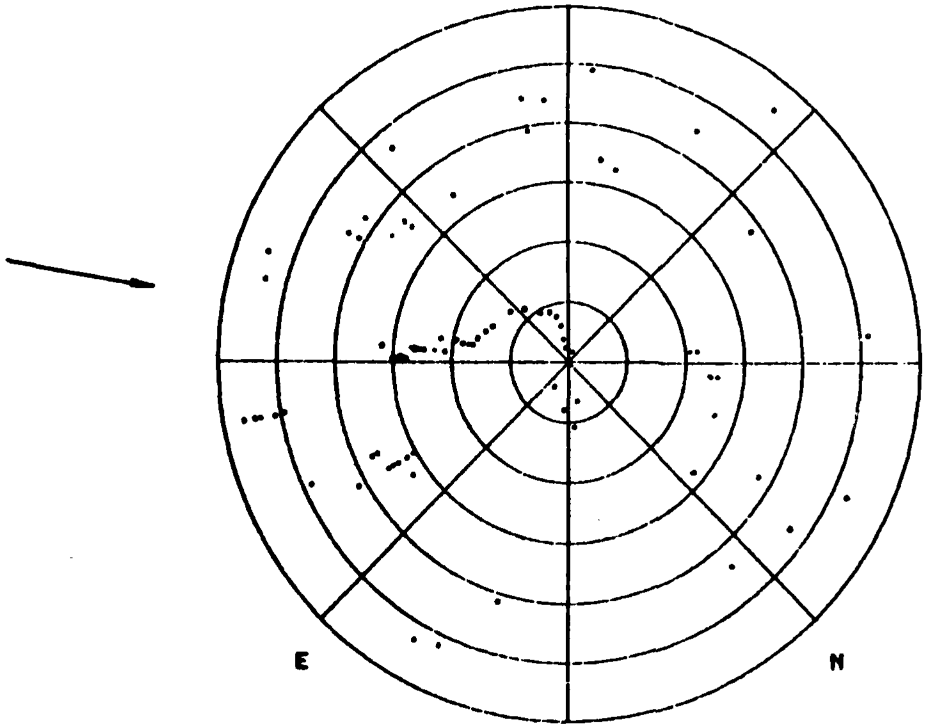
E
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



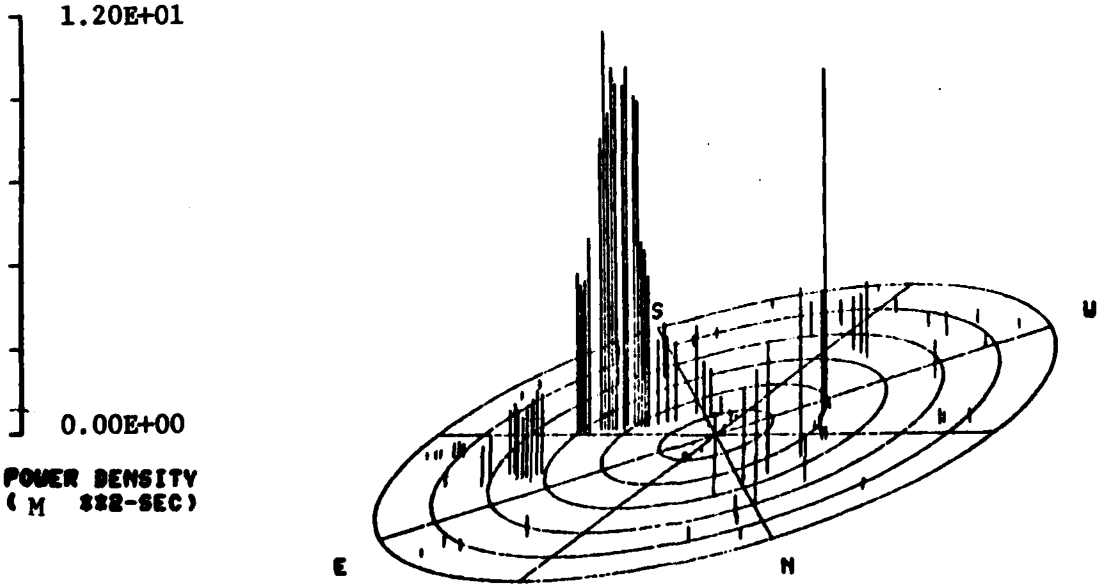
E
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 4900.: 3054.0 - 4448.0 256 FREQUENCIES
TRANSDUCERS : 1 NORTH 1 WEST 1 EAST



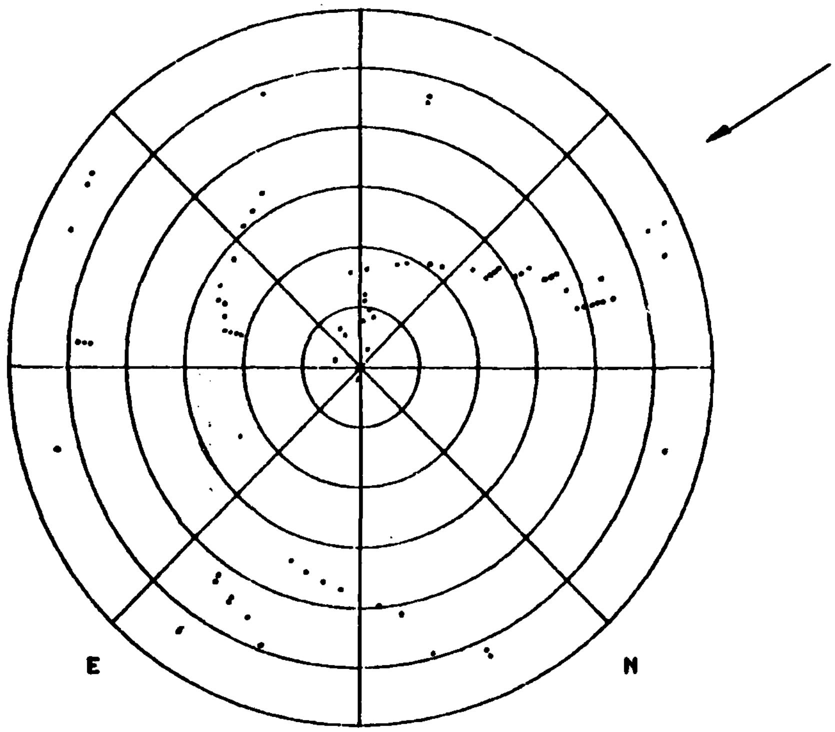
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



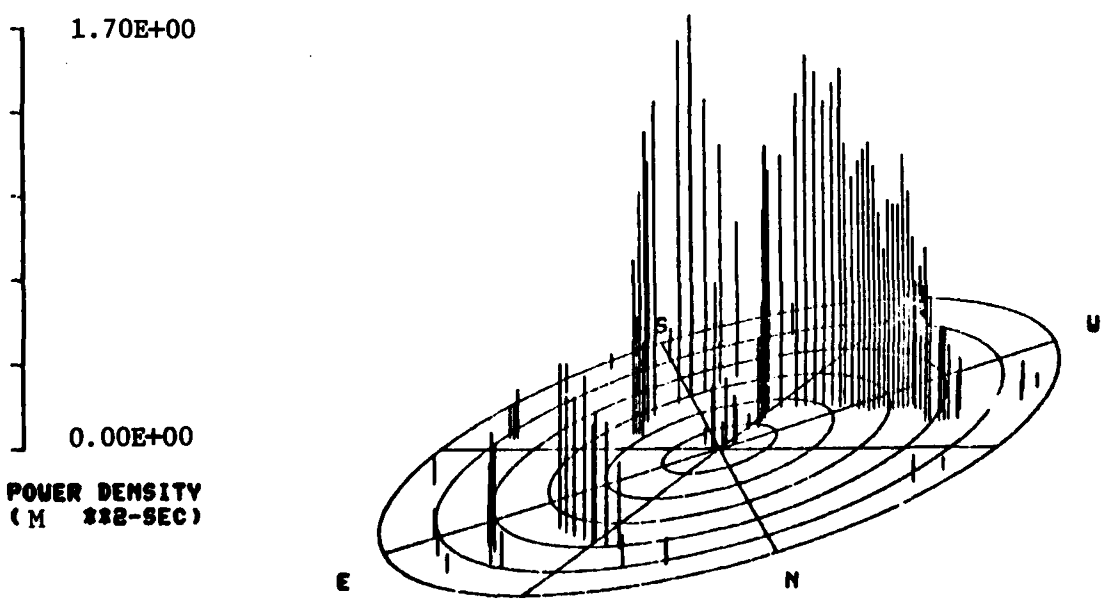
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 11700.: 6767.0 - 10367.0 256 FREQUENCIES
TRANSDUCERS : 2 WEST 2 SOUTH 2 EAST



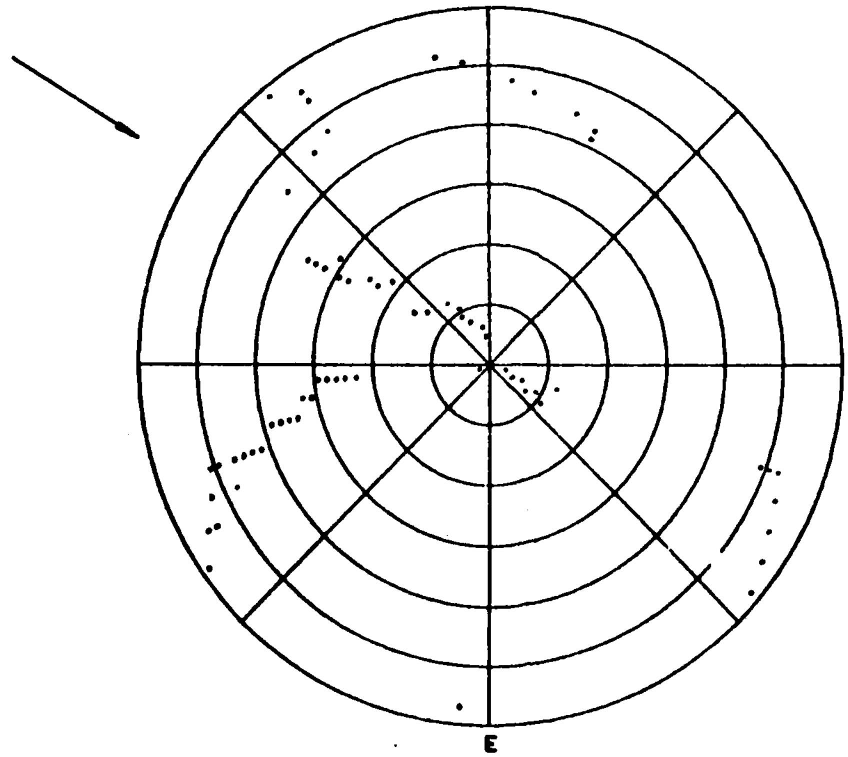
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION



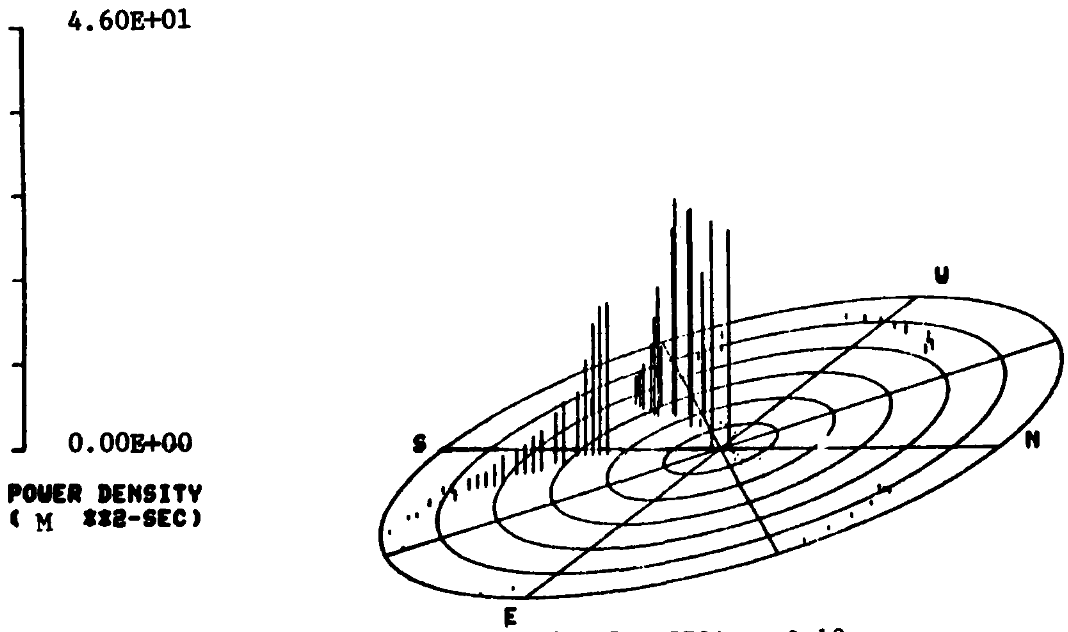
FREQUENCY (RAD/SEC): 0.20
PER RADIAL DIVISION

GULF OF MEXICO - DIRECTIONAL WAVE SPECTRUM

RUN : 3.: 0.0 - 7292.6 256 FREQUENCIES
TRANSDUCERS : 1NORTHWH 1WEST WH 1SOUTHWH 1EAST WH



FREQUENCY (RAD/SEC): 0.12
PER RADIAL DIVISION



FREQUENCY (RAD/SEC): 0.12
PER RADIAL DIVISION

APPENDIX C

Ocean Station INDIA Wave Spectra Plots and Statistics

STATION INDIA

Run No.: NW 120

Wave Height Spectrum

Weather Reporter

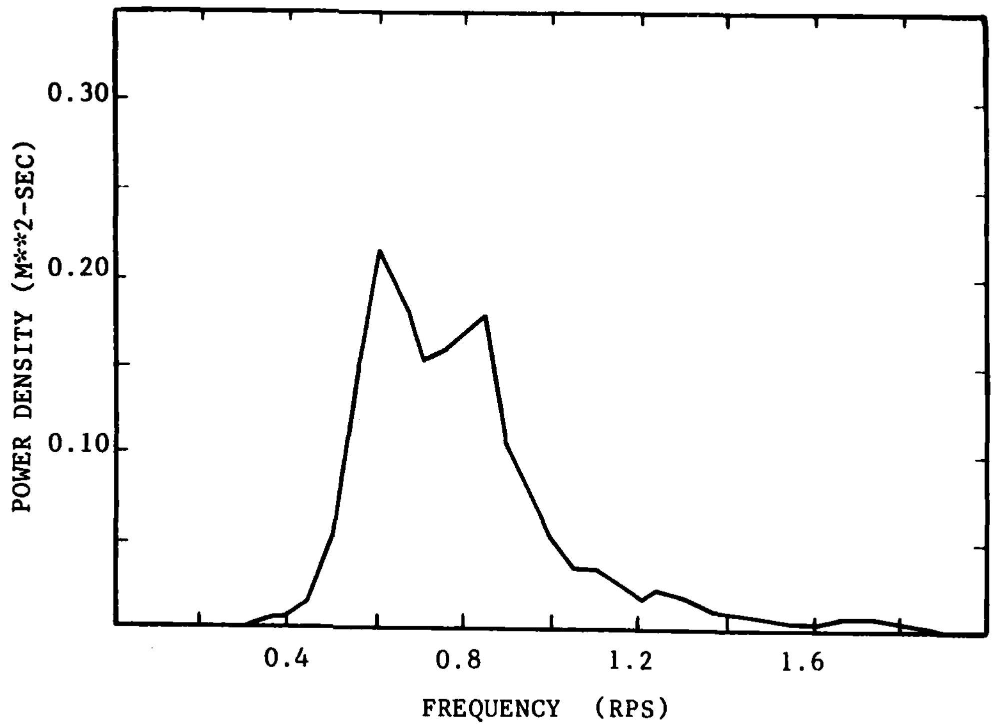
May 4, 1959

Sea State 3 Medium

Sig. DA: 1.17 M

Amp. Max.: .20

Freq Max.: .60



Run No.: NW 129

Wave Height Spectrum

Weather Reporter

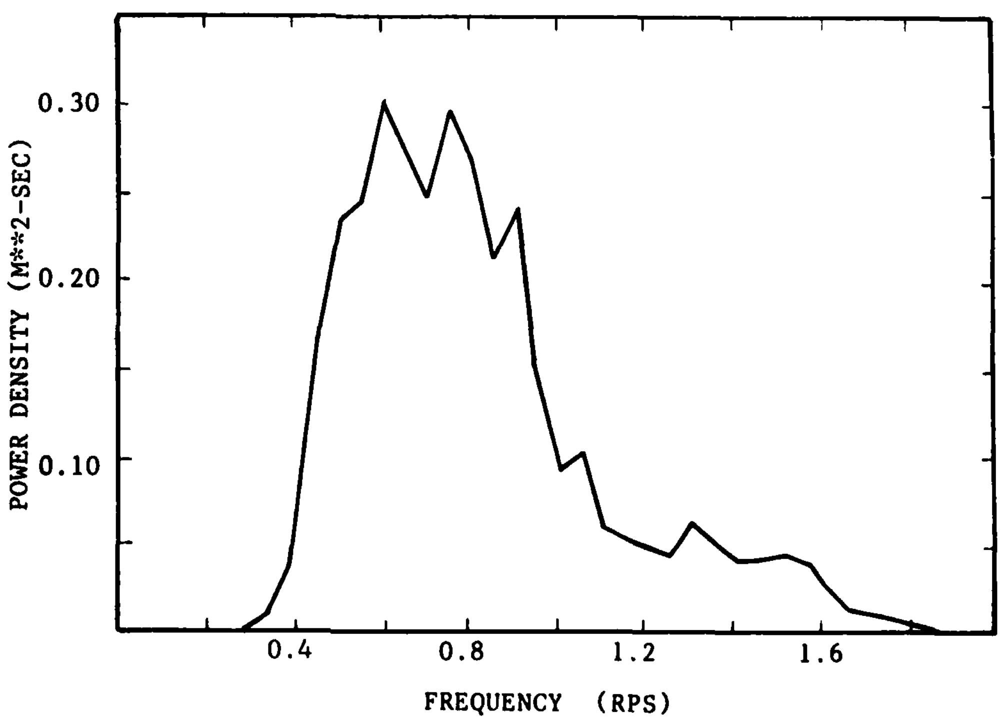
May 23, 1960

Sea State 4 Low

Sig. DA: 1.65 M

Amp. Max.: .27

Freq. Max.: .60



STATION INDIA

Run No.: NW 138

Wave Height Spectrum

Weather Reporter

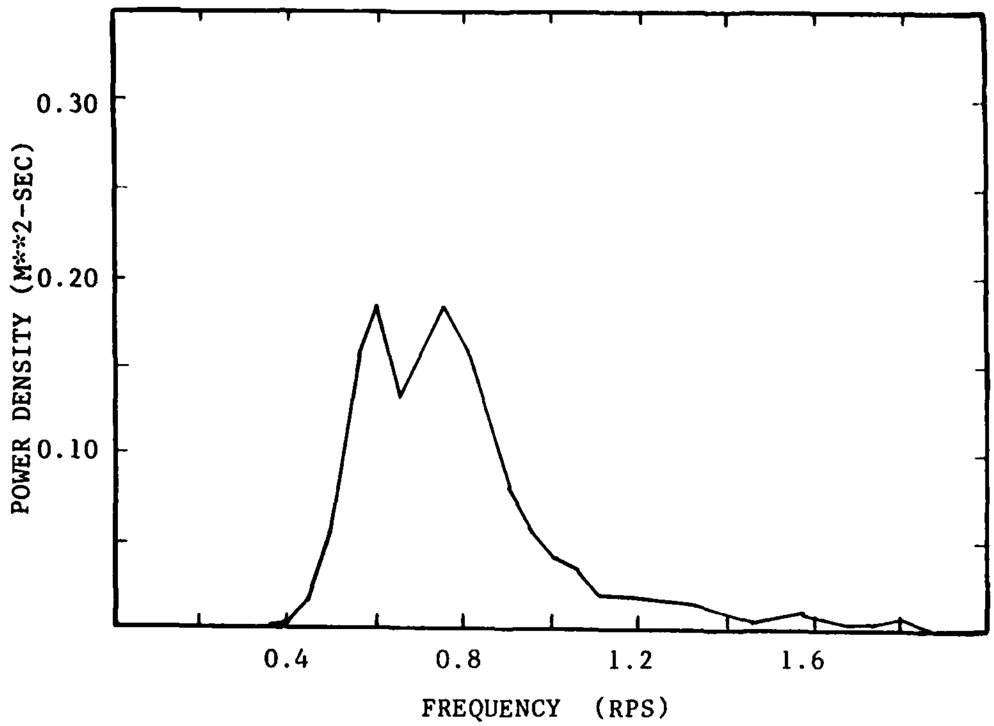
August 29, 1960

Sea State 3 Medium

Sig. DA: 1.11 M

Amp. Max.: .17

Freq Max.: .60



Run No.: NW 217

Wave Height Spectrum

Weather Reporter

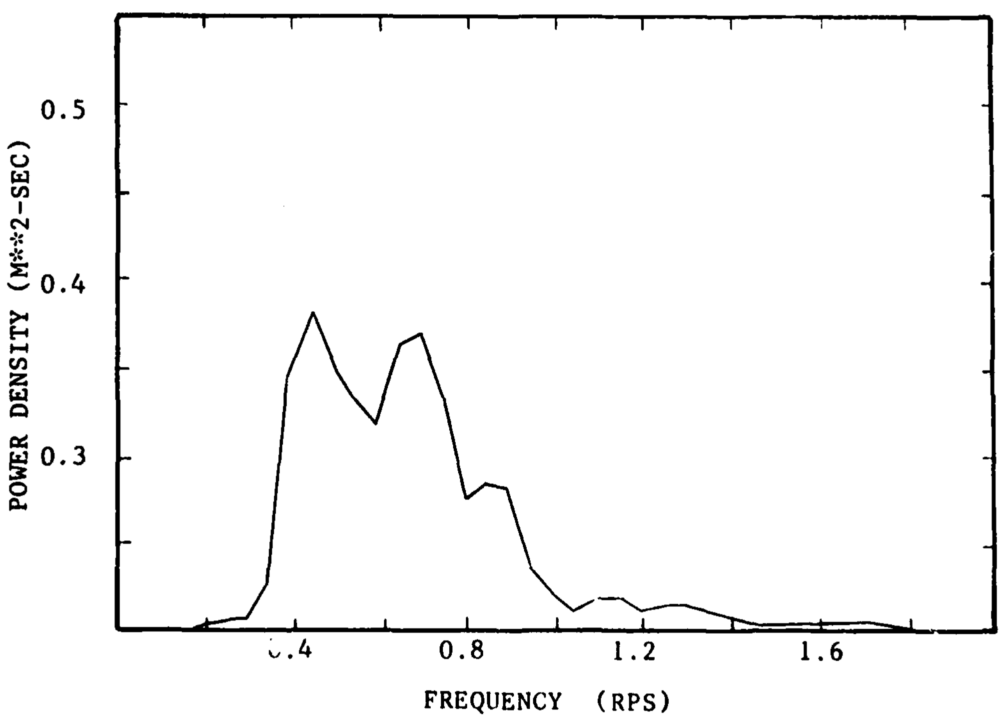
November 5, 1964

Sea State 4 Low

Sig. DA: 1.64 M

Amp. Max.: .36

Freq. Max.: .45



Run No.: NW 018

Wave Height Spectrum

Weather Reporter

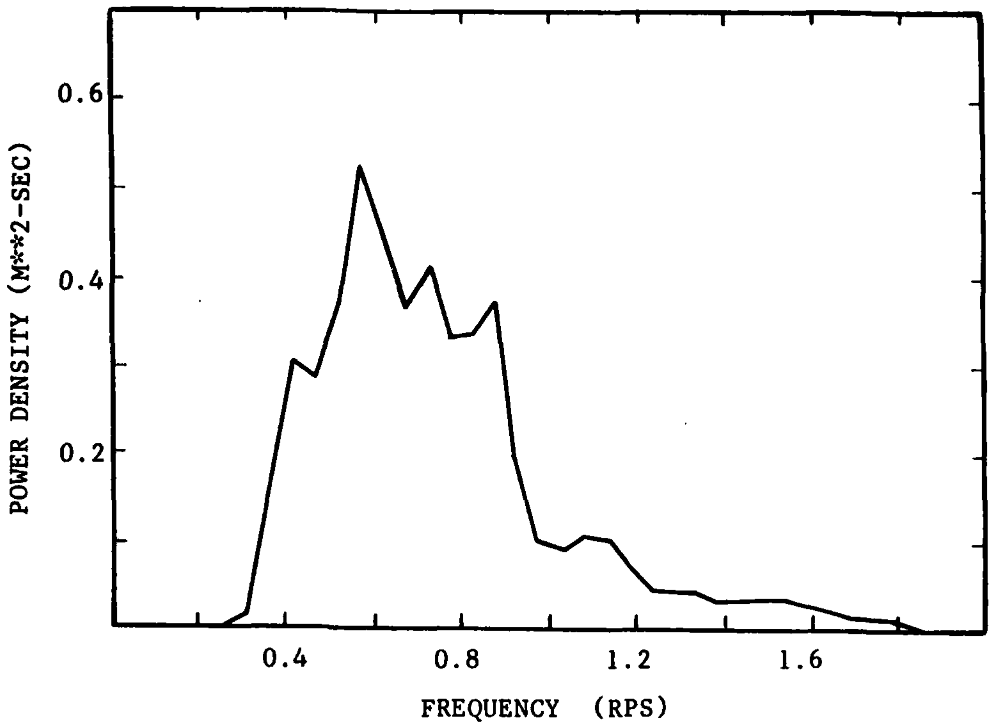
January 14, 1963

Sea State 4 Medium

Sig. DA: 1.96 M

Amp. Max.: .46

Freq Max.: .55



Run No.: NW 038

Wave Height Spectrum

Weather Reporter

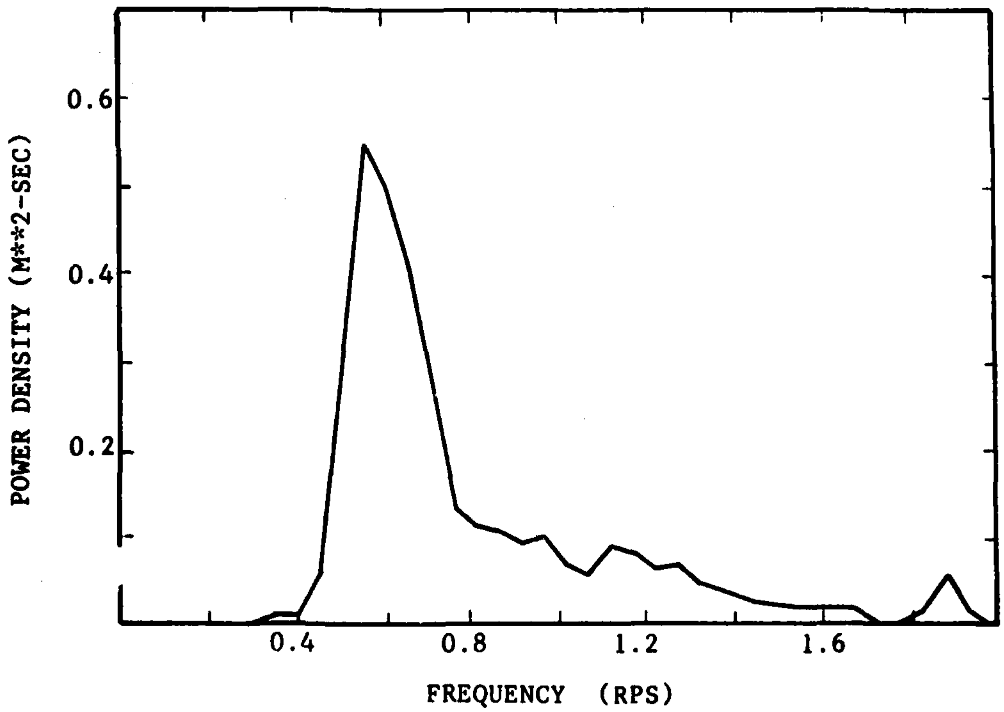
April 23, 1955

Sea State 4 Low

Sig. DA: 1.62 M

Amp. Max.: .42

Freq. Max.: .55



Run No.: NW 064

Wave Height Spectrum

Weather Reporter

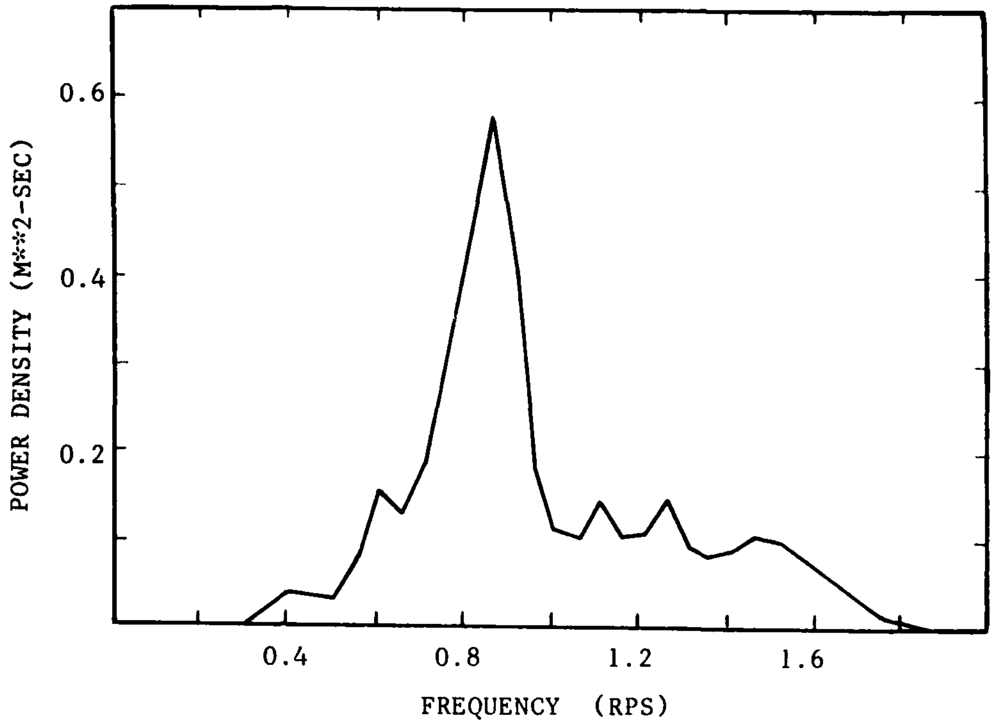
August 12, 1956

Sea State 4 Medium

Sig. DA: 1.80 M

Amp. Max.: .26

Freq Max.: .85



Run No.: NW 163

Wave Height Spectrum

Weather Reporter

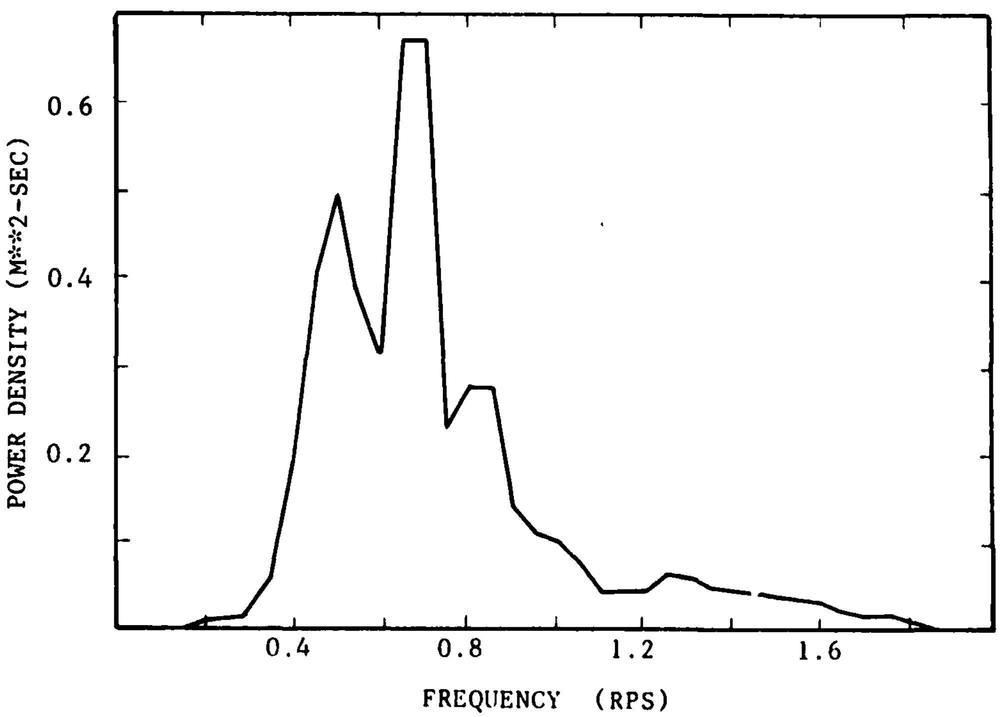
January 20, 1961

Sea State 4 High

Sig. DA: 1.98 M

Amp. Max.: .58

Freq. Max.: .85



Run No.: NW 145

<u>Wave Height Spectrum</u>

Weather Reporter

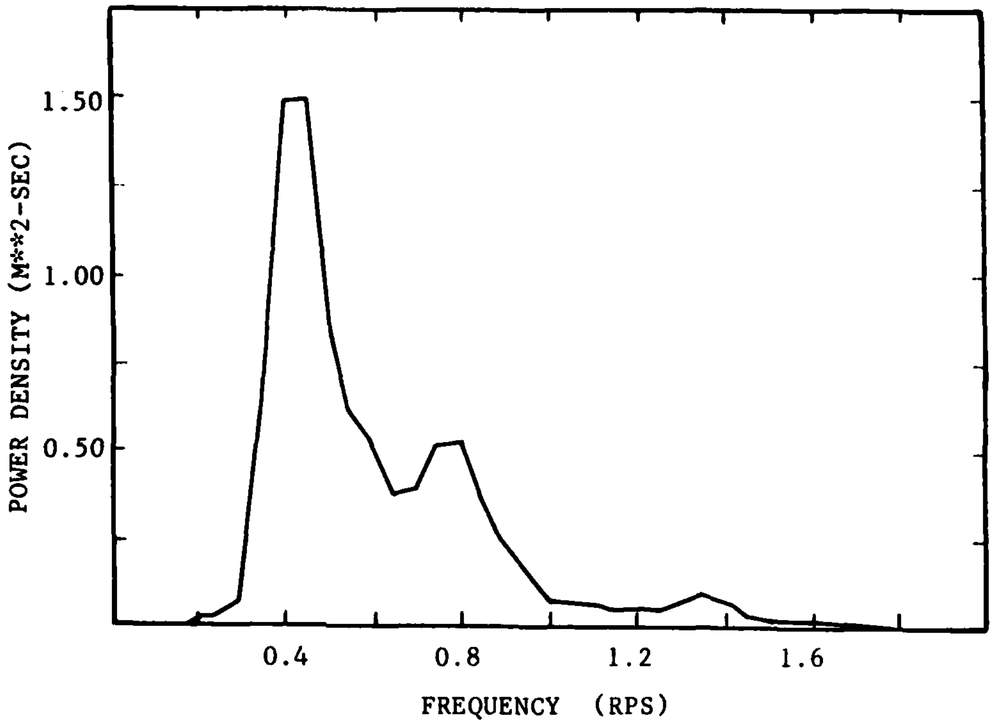
November 21, 1960

Sea State 5 Low

Sig. DA: 2.67 M

Amp. Max.: 1.45

Freq Max.: .45



Run No.: NW 247

<u>Wave Height Spectrum</u>

Weather Reporter

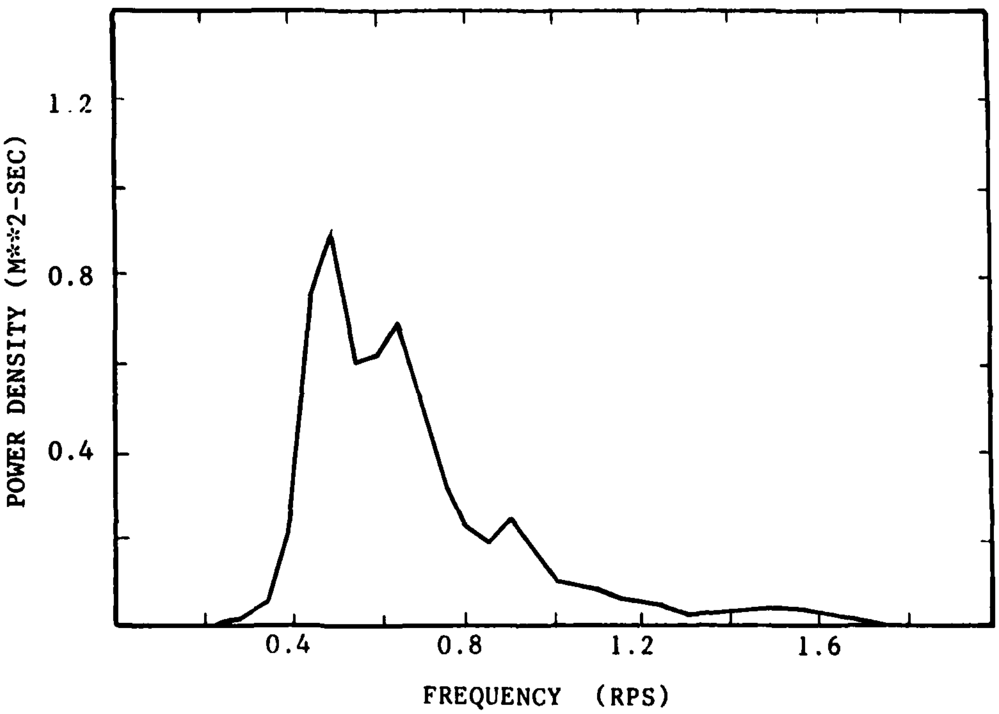
October 1, 1965

Sea State 5 Low

Sig. DA: 2.34 M

Amp. Max.: .87

Freq. Max.: .50



Run No.: NW 271

<u>Wave Height Spectrum</u>

Weather Reporter

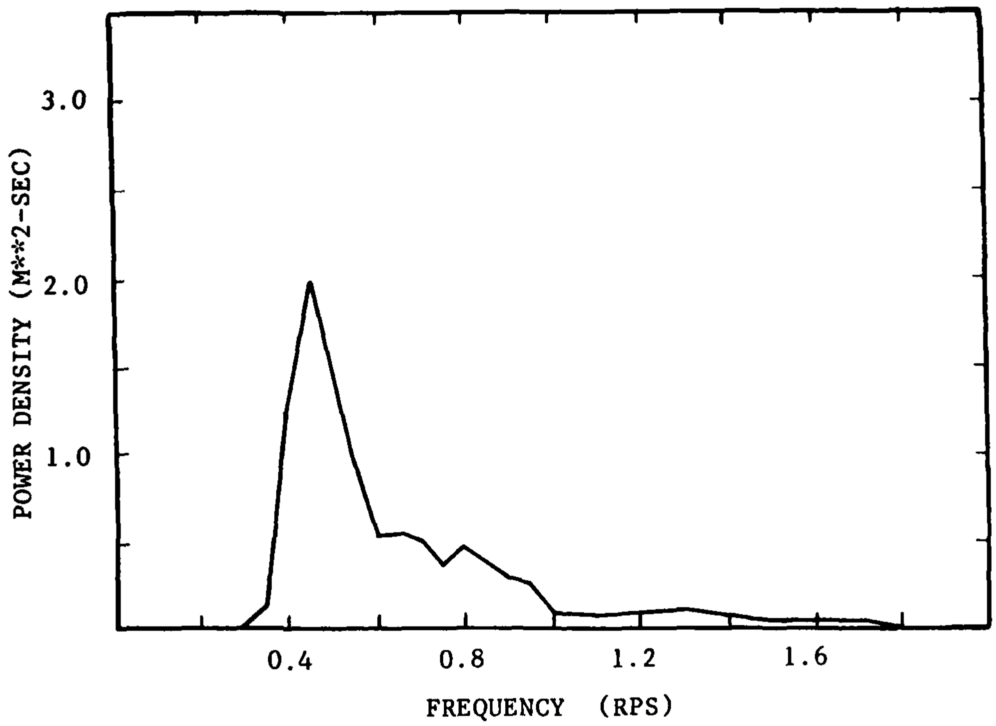
January 31, 1967

Sea State 5 Medium

Sig. DA: 2.85 M

Amp. Max.: 1.93

Freq Max.: .45



Run No.: NW 301

<u>Wave Height Spectrum</u>

Weather Reporter

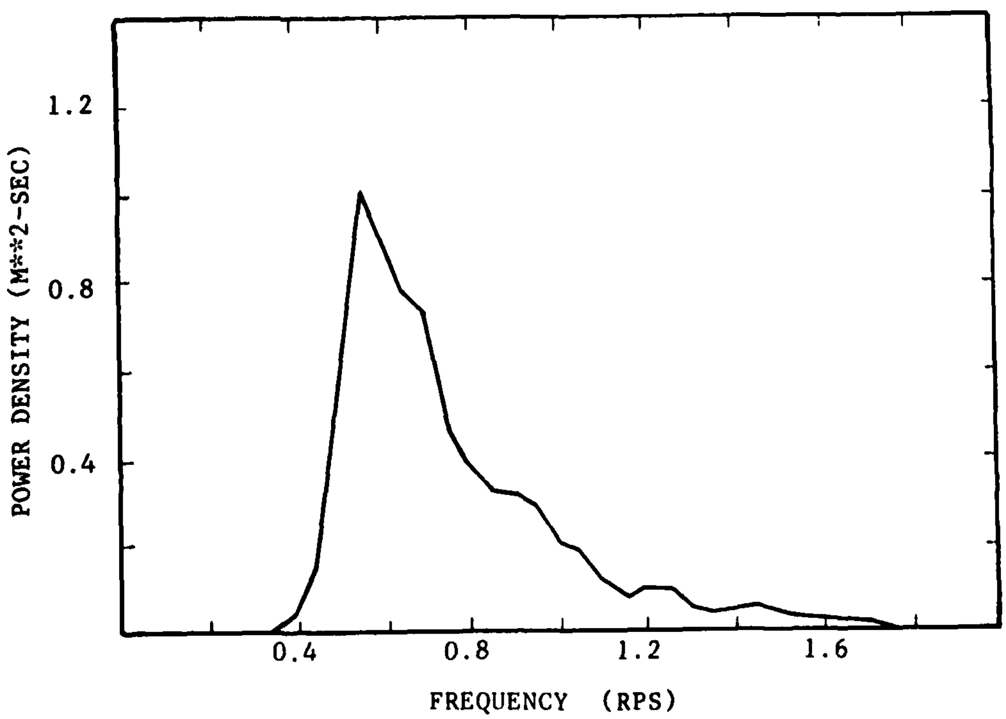
May 7, 1967

Sea State 5 Low

Sig. DA: 2.39 M

Amp. Max.: .98

Freq. Max.: .55



STATION INDIA

Run No.: NW 010

<u>Wave Height Spectrum</u>

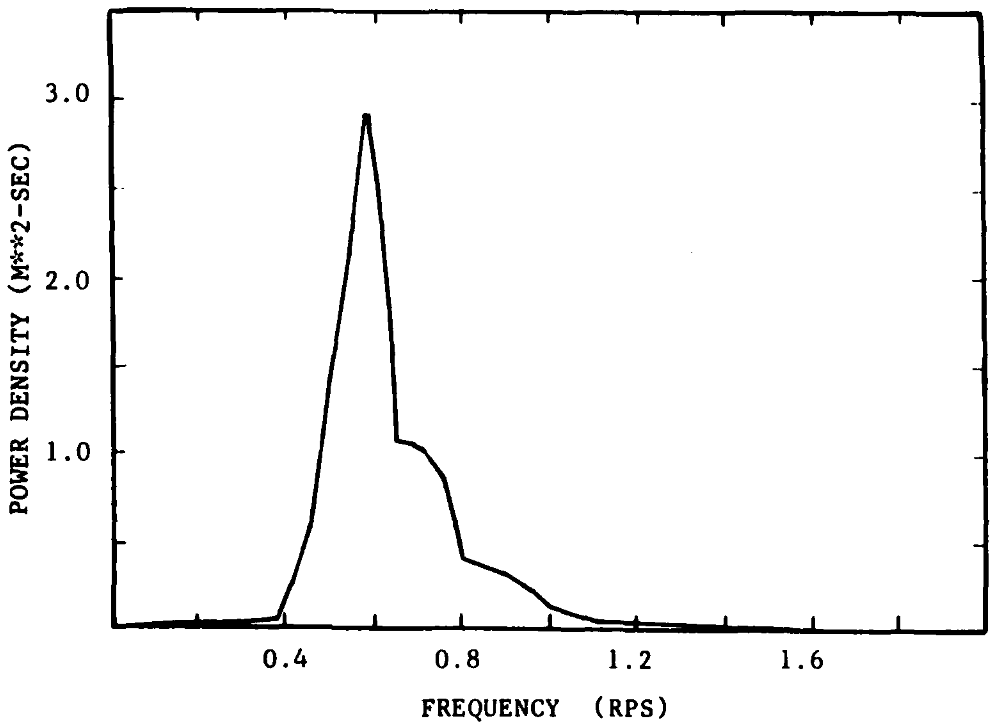
Weather Reporter

Sea State 5 High

Sig. DA: 3.70 M

Amp. Max.: .06

Freq Max.: .35



Run No.: NW 014

<u>Wave Height Spectrum</u>

Weather Reporter

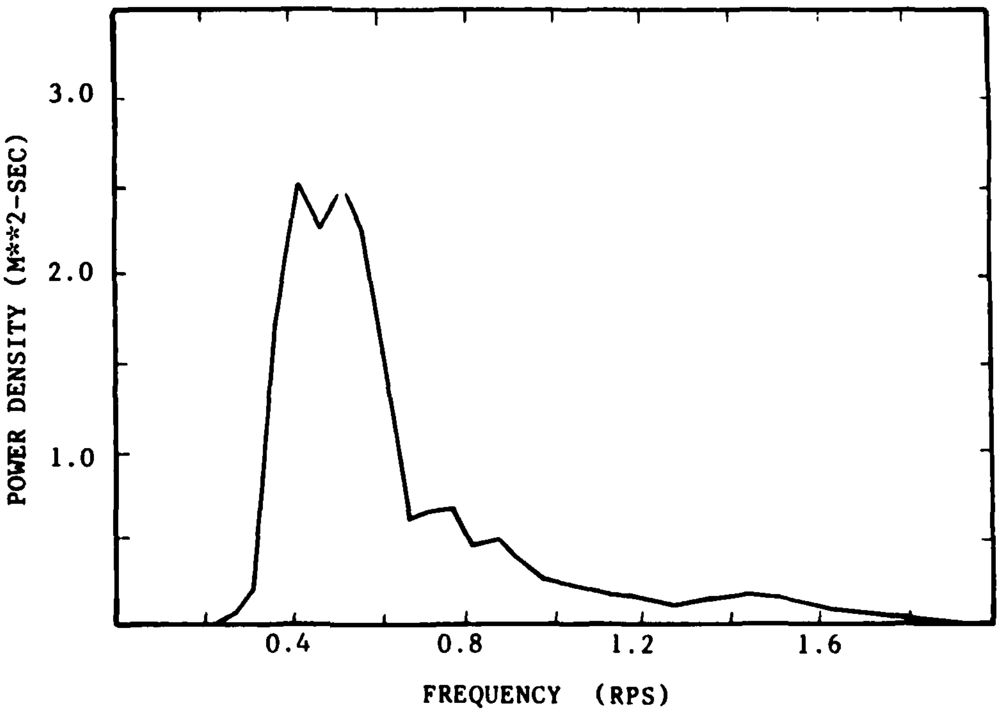
January 10, 1963

Sea State 6 Low

Sig. DA: 3.81 M

Amp. Max.: 2.42

Freq. Max.: .40



STATION INDIA

Run No.: NW 151

Wave Height Spectrum

Weather Reporter

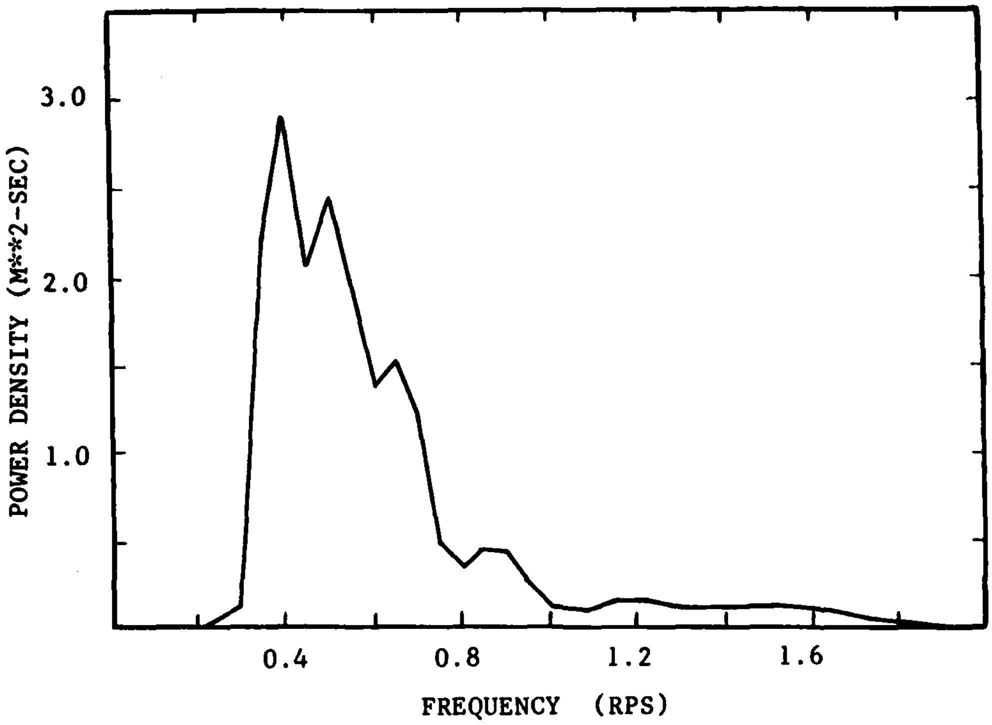
December 4, 1960

Sea State 6 Low

Sig. DA: 3.93 M

Amp. Max.: 2.82

Freq Max.: .40



Run No.: NW 230

Wave Height Spectrum

Weather Reporter

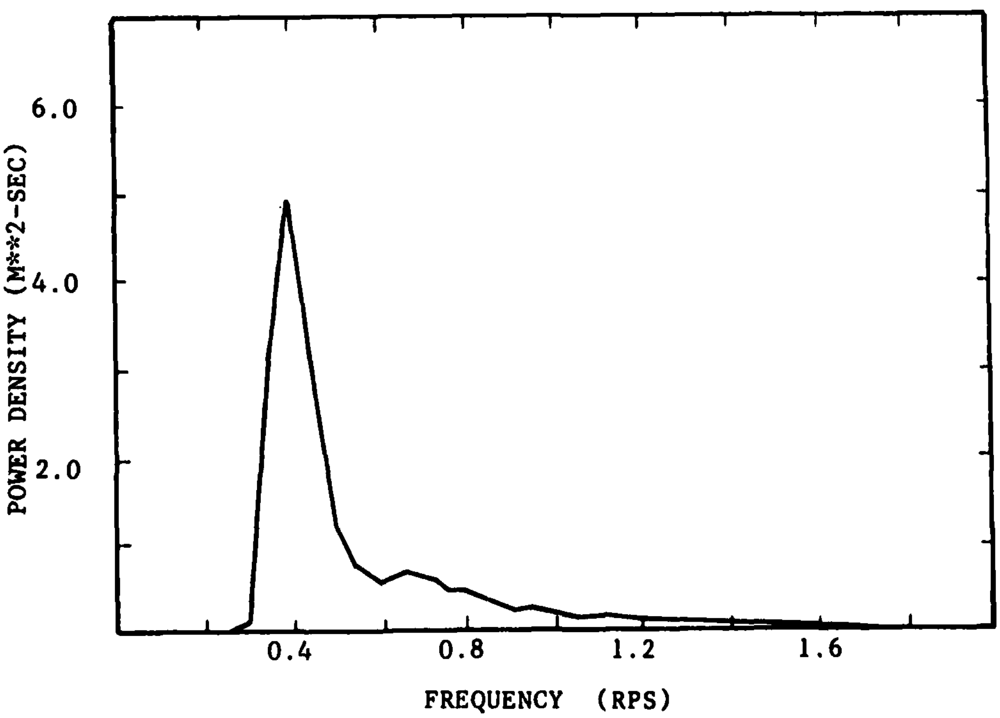
April 5, 1965

Sea State 5 High

Sig. DA: 3.68 M

Amp. Max.: 4.88

Freq. Max.: .40



Run No.: NW 063

Wave Height Spectrum

Weather Reporter

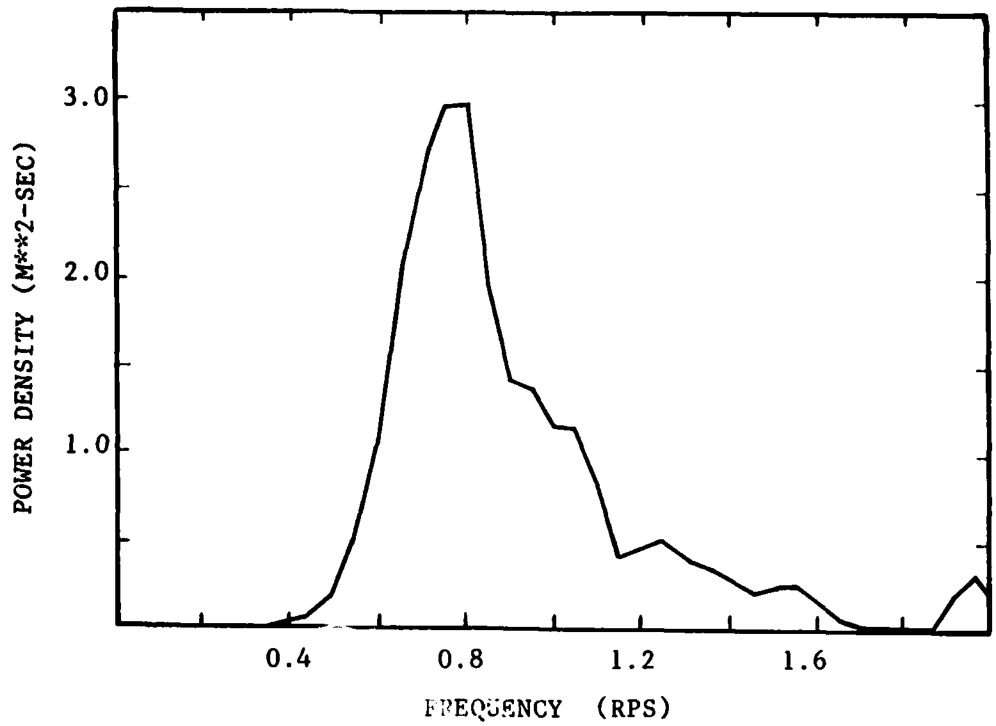
August 11, 1982

Sea State 6 Medium

Sig. DA: 4.39 M

Amp. Max.: 1.63

Freq Max.: .75



Run No.: NW 192

Wave Height Spectrum

Weather Reporter

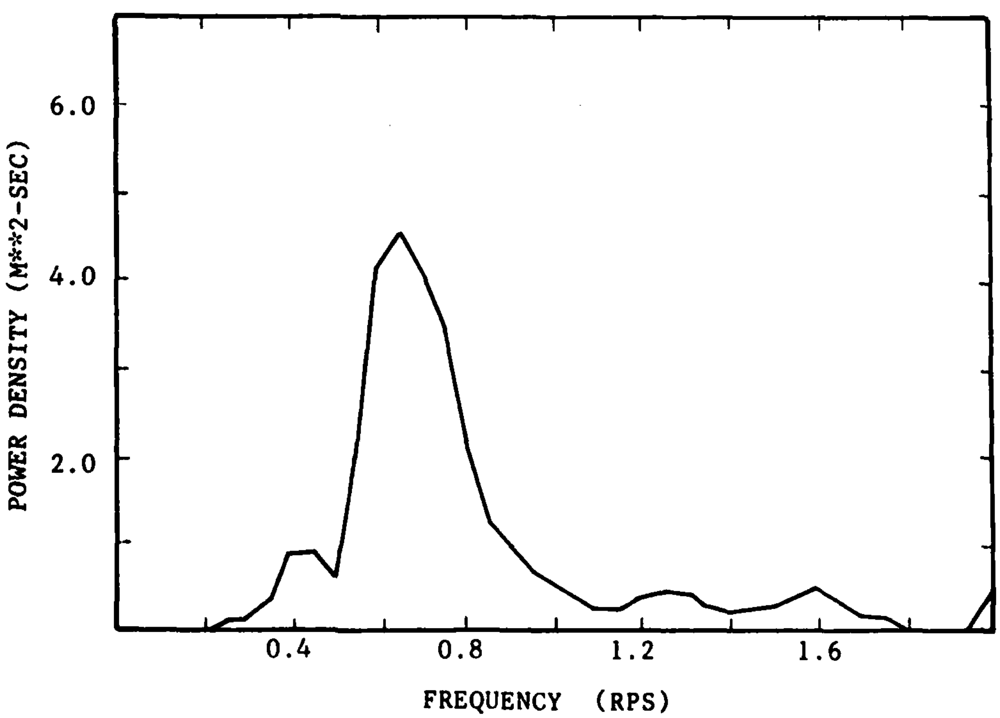
January 15, 1982

Sea State 6 High

Sig. DA: 5.04 M

Amp. Max.: 3.99

Freq. Max.: .65



Run No.: NW 218

Wave Height Spectrum

Weather Reporter

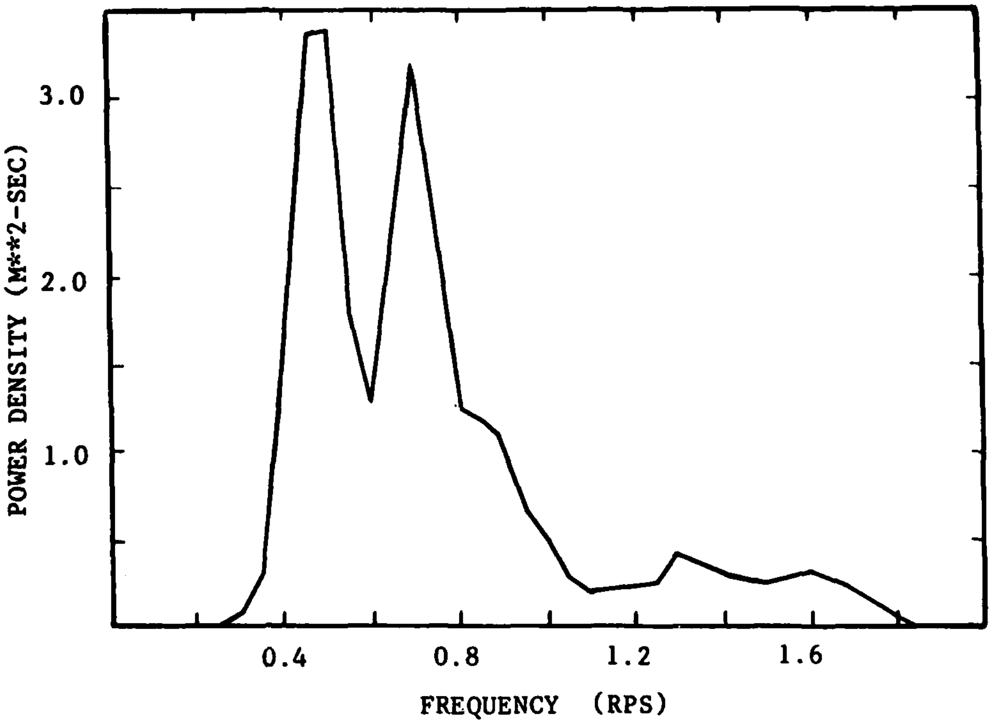
November 8, 1964

Sea State 6 Medium

Sig. DA: 4.69 M

Amp. Max.: 3.30

Freq Max.: .45



Run No.: NW 224

Wave Height Spectrum

Weather Reporter

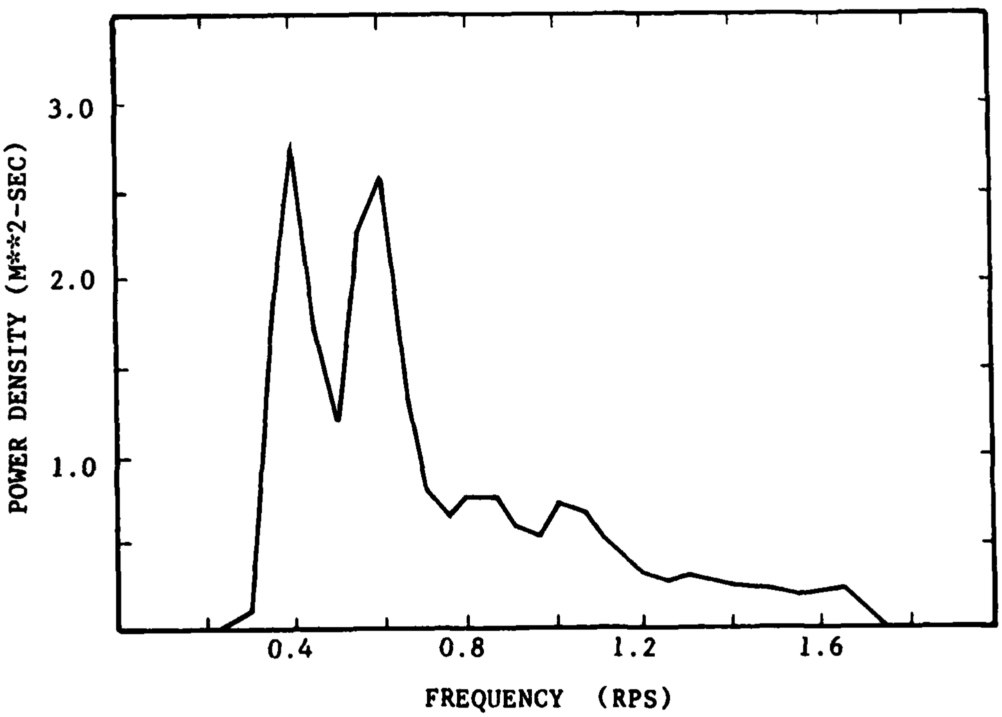
March 19, 1965

Sea State 6 Medium

Sig. DA: 4.28

Amp. Max.: 2.80

Freq. Max.: .40



STATION INDIA

Run No.: NW 069

Wave Height Spectrum

Weather Reporter

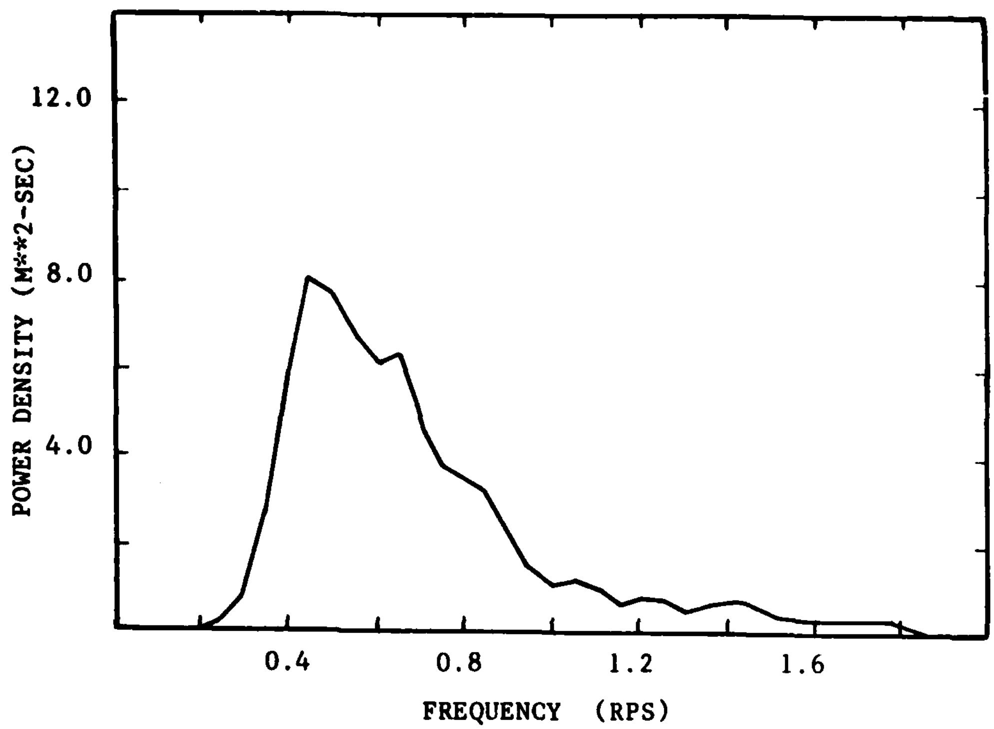
November 10, 1956

Sea State 7 Low

Sig. DA: 7.60 M

Amp. Max.: 6.88

Freq Max.: .45



Run No.: NW 173

Wave Height Spectrum

Weather Reporter

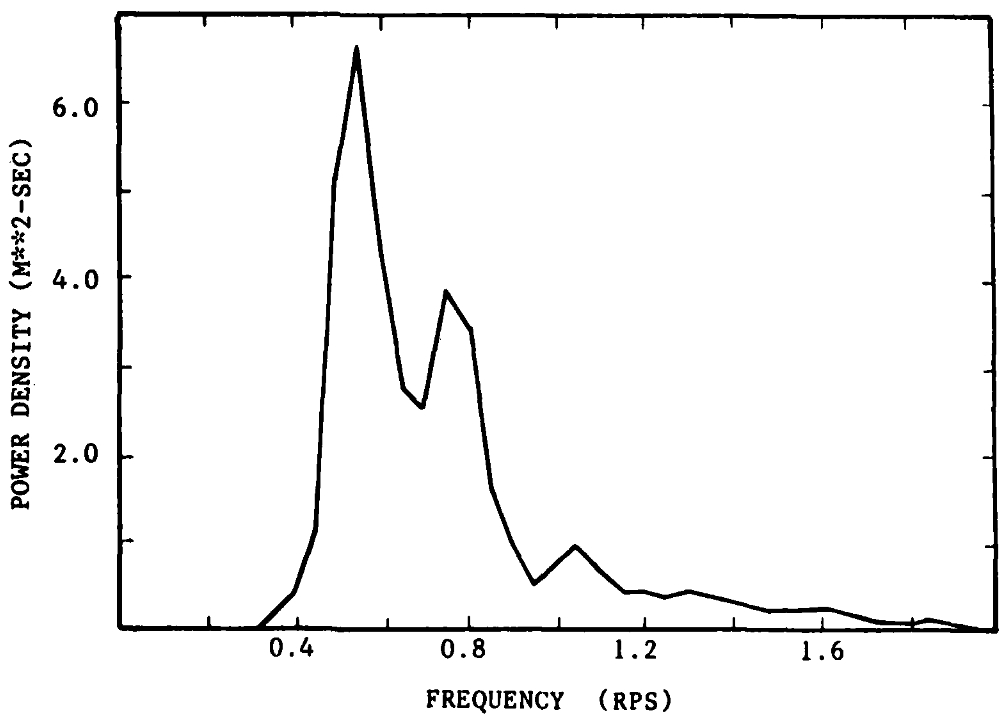
June 17, 1961

Sea State 7 Low

Sig. DA: 5.55 M

Amp. Max.: 6.45

Freq. Max.: .55



Run No.: NW 176

Wave Height Spectrum

Weather Reporter

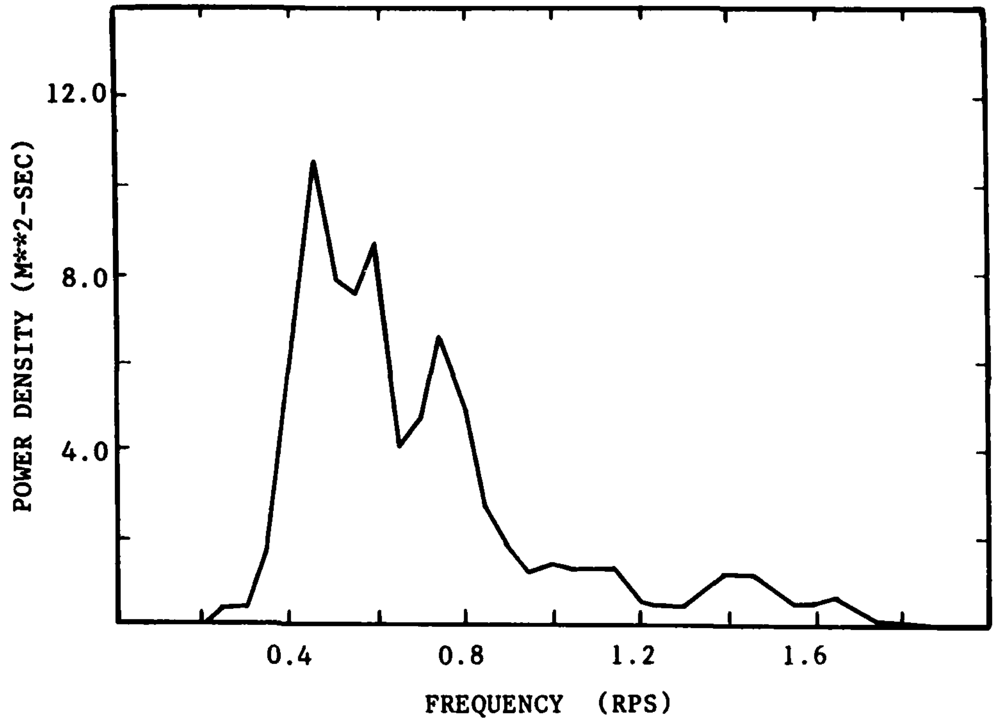
December 8, 1961

Sea State 7 Medium

Sig. DA: 8.10 M

Amp. Max.: 10.76

Freq Max.: .45



Run No.: NW 309

Wave Height Spectrum

Weather Reporter

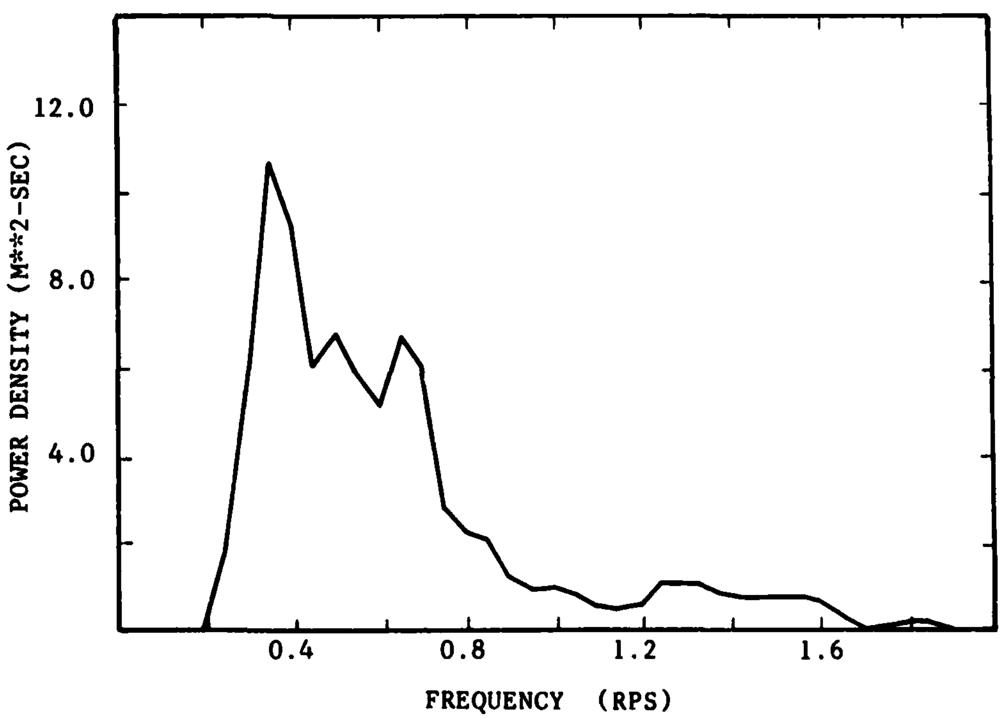
January 26, 1961

Sea State 7 Medium

Sig. DA: 8.18 M

Amp. Max.: 10.29

Freq. Max.: .35



STATION INDIA

Run No.: NW 025

Wave Height Spectrum

Weather Reporter

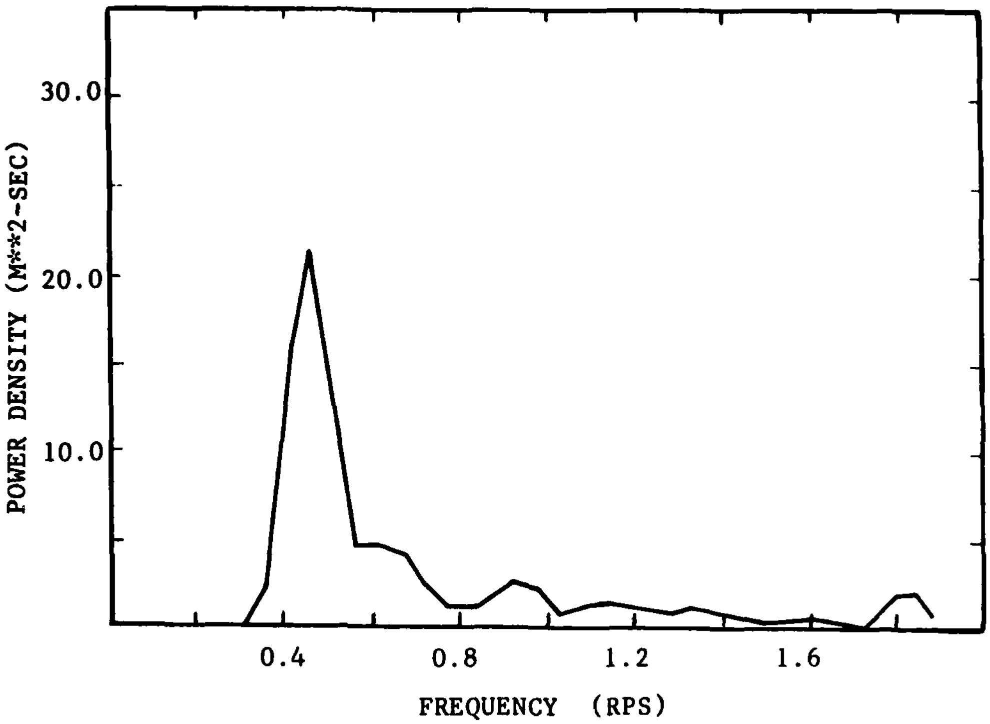
October 10, 1954

Sea State 7 Medium

Sig. DA: 8.46 M

Amp. Max.: 13.19

Freq Max.: .40



Run No.: NW 034

Wave Height Spectrum

Weather Reporter

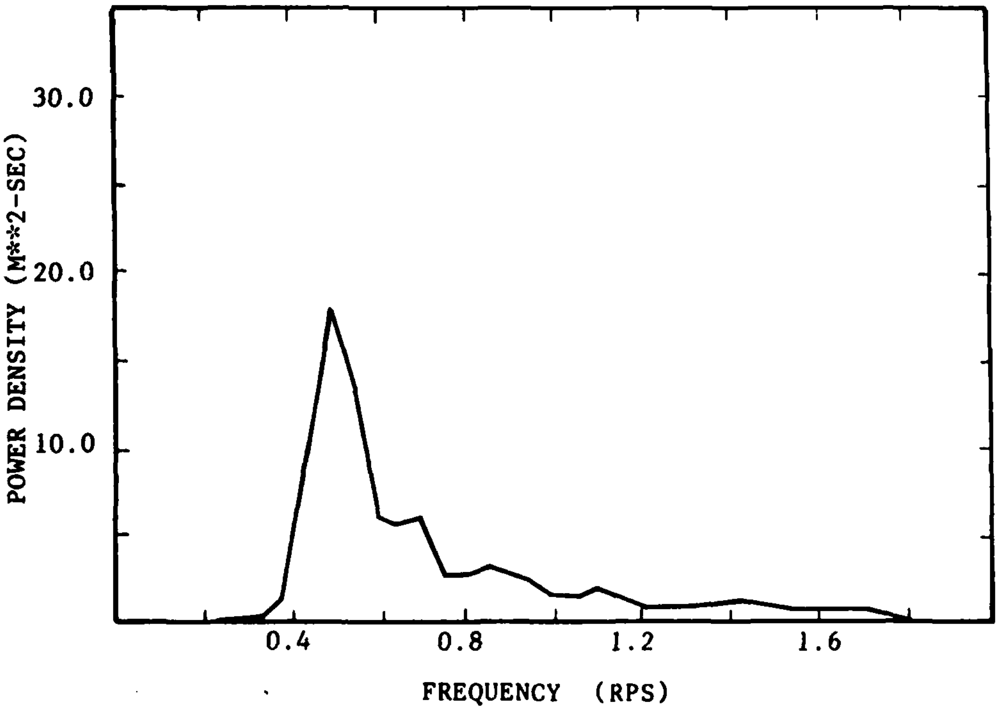
April 12, 1955

Sea State 7 Medium

Sig. DA: 8.46 M

Amp. Max.: 14.81

Freq. Max.: .50



STATION INDIA

Run No.: NW 184

Wave Height Spectrum

Weather Reporter

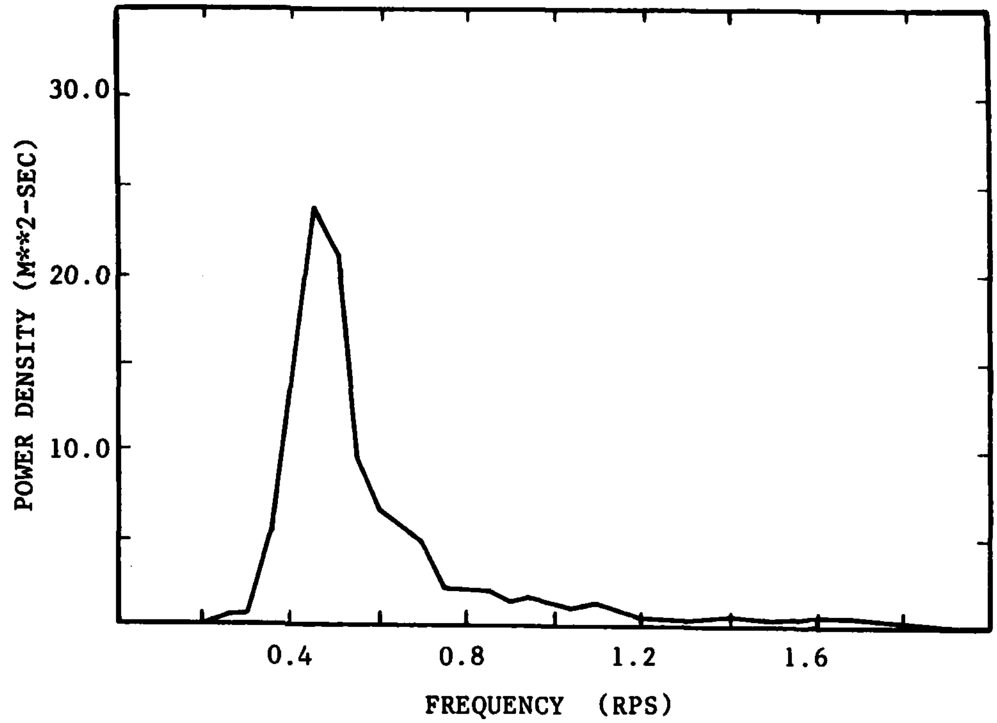
January 22, 1962

Sea State 7 Medium

Sig. DA: 9.22 M

Amp. Max.: 23.80

Freq Max.: .45



Run No.: NW 295

Wave Height Spectrum

Weather Reporter

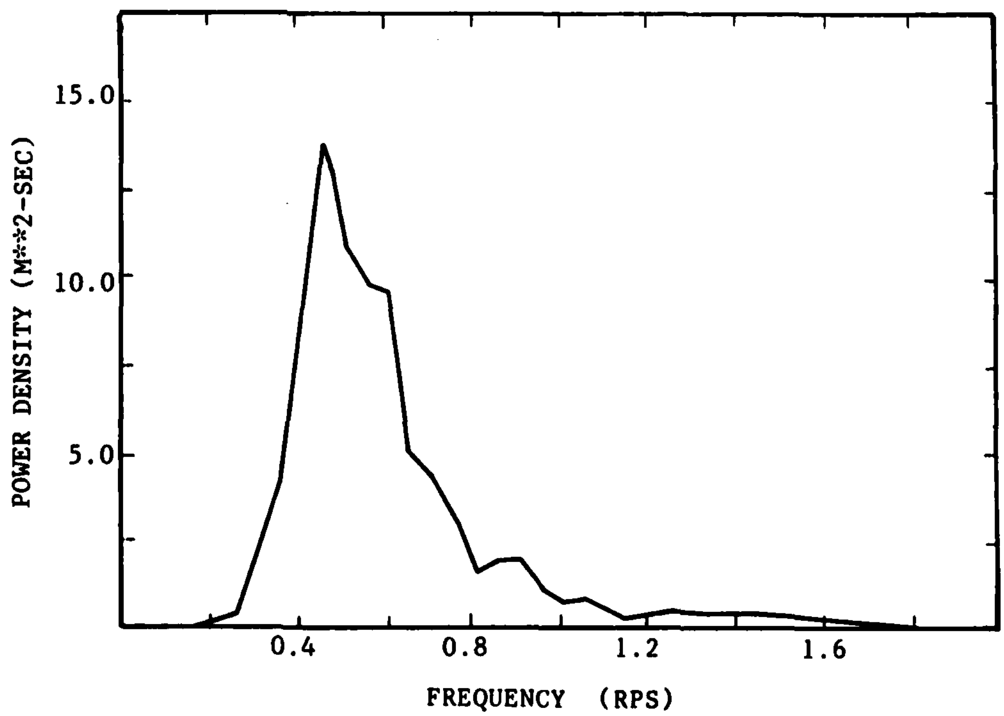
April 24, 1967

Sea State 7 Medium

Sig. DA: 8.28 M

Amp. Max.: 13.79

Freq. Max.: .45



STATION INDIA

Run No.: NW 149

Wave Height Spectrum

Weather Reporter

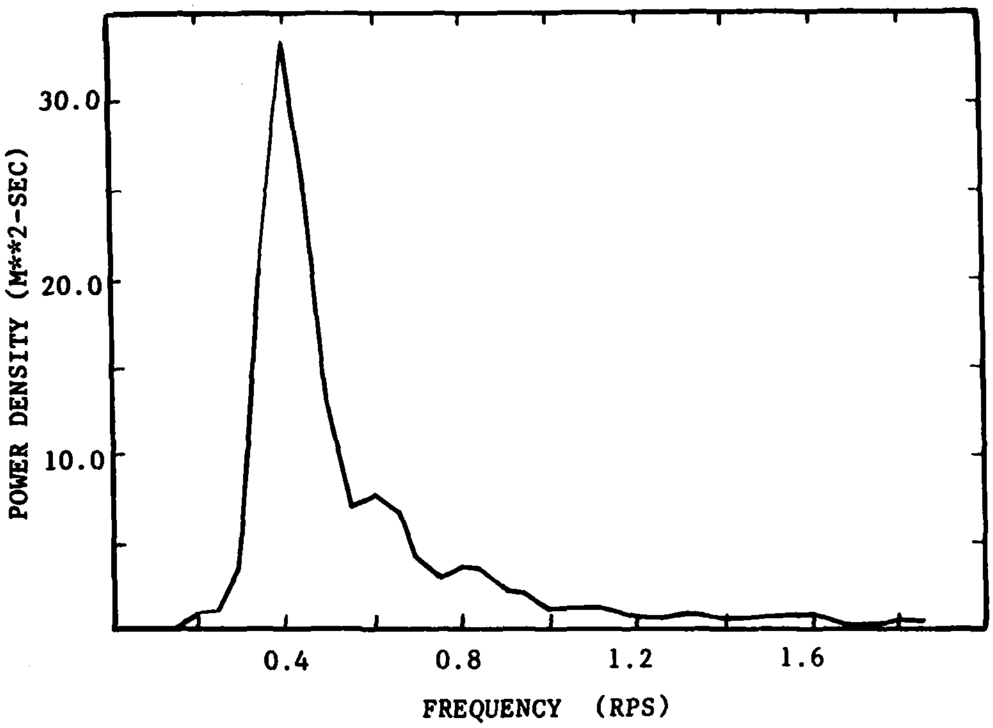
December 3, 1960

Sea State 7 High

Sig. DA: 10.70 M

Amp. Max.: 31.99

Freq Max.: .40



Run No.: NW 187

Wave Height Spectrum

Weather Reporter

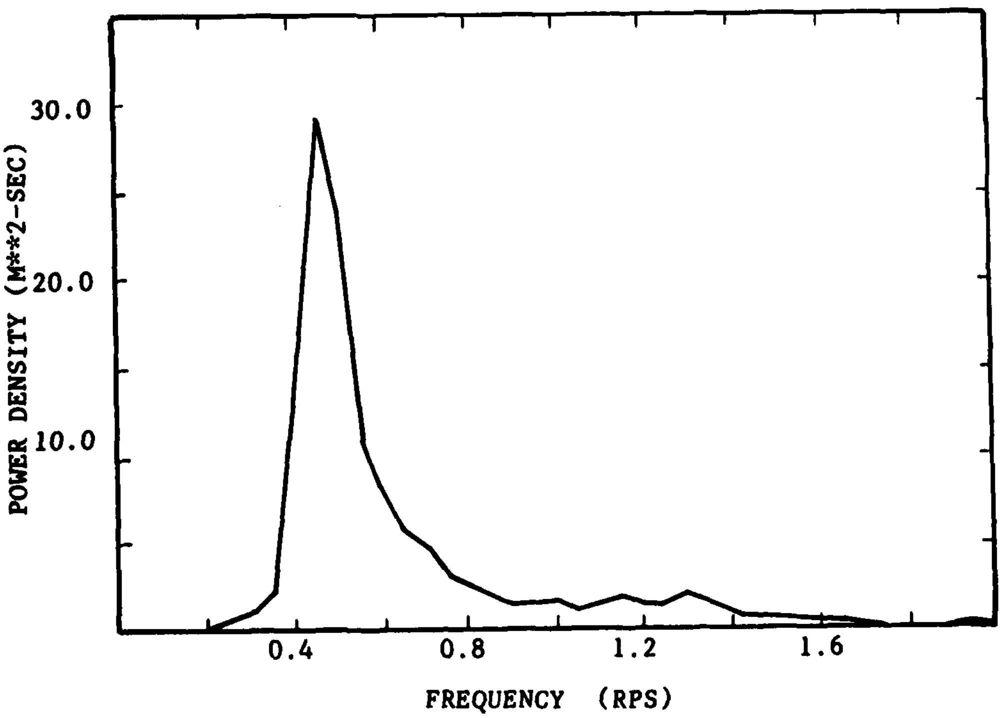
January 31, 1962

Sea State 7 High

Sig. DA: 10.05 M

Amp. Max.: 29.11

Freq. Max.: .45



STATION INDIA

Run No.: NW 190

Wave Height Spectrum

Weather Reporter

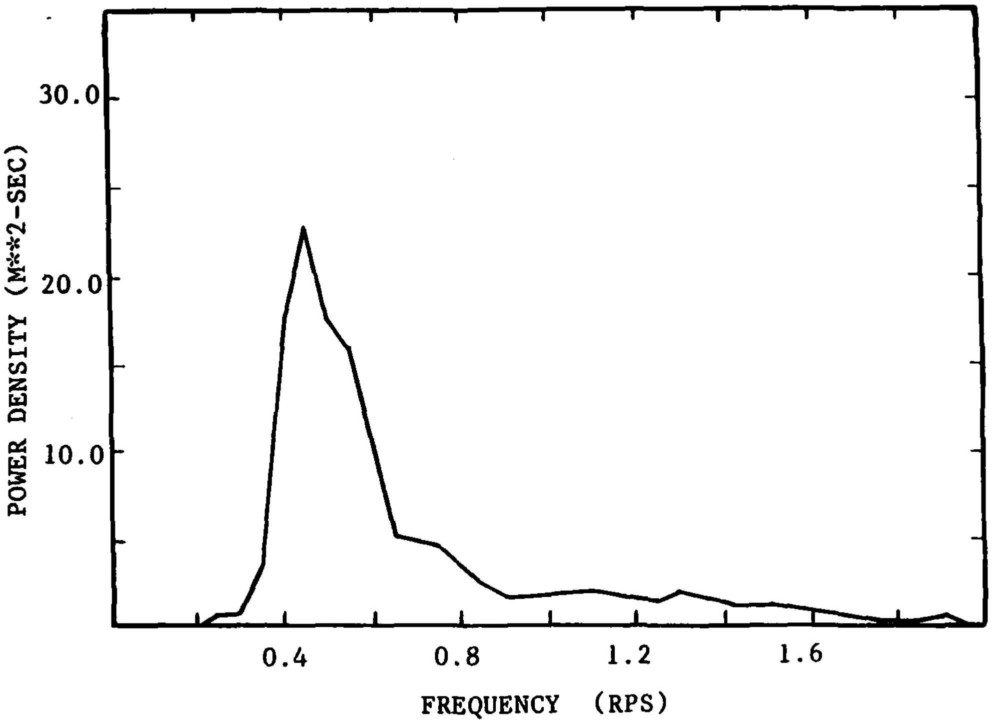
February 11, 1962

Sea State 7 High

Sig. DA: 10.08 M

Amp. Max.: 22.36

Freq Max.: .45



Run No.: NW 314

Wave Height Spectrum

Weather Reporter

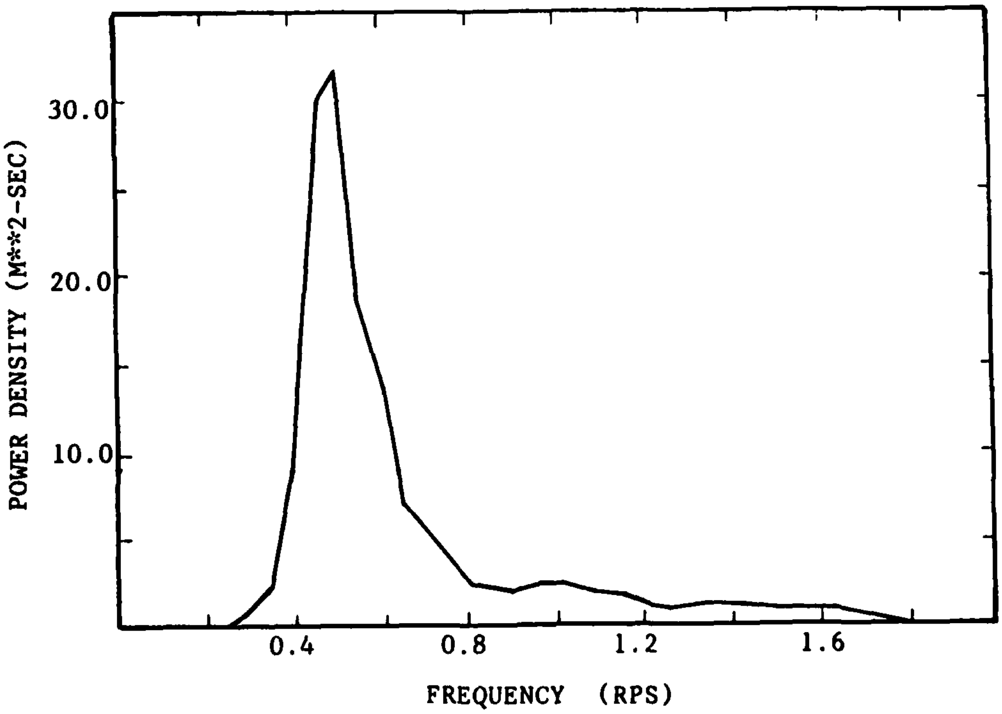
June 16, 1961

Sea State 7 High

Sig. DA: 10.81 M

Amp. Max.: 30.28

Freq. Max.: .50



STATION INDIA

Run No.: NW 198

Wave Height Spectrum

Weather Reporter

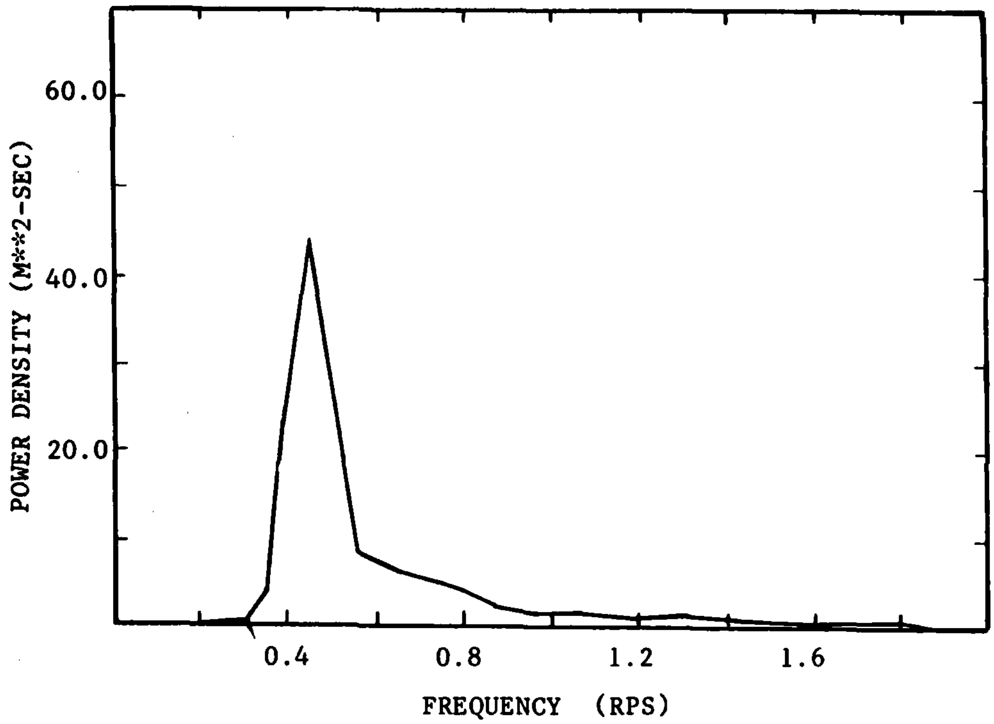
January 30, 1964

Sea State 7 High

Sig. DA: 11.33 M

Amp. Max.: 44.31

Freq Max.: .45



Run No.: NW 304

Wave Height Spectrum

Weather Reporter

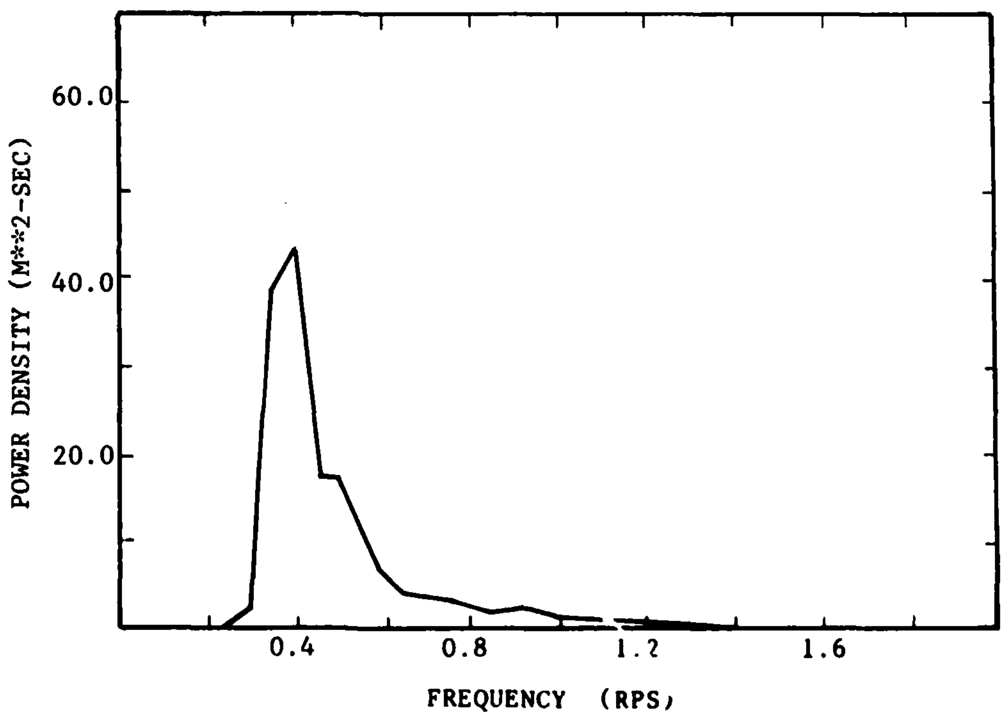
December 6, 1966

Sea State 7 High

Sig. DA: 11.49 M

Amp. Max.: 42.23

Freq. Max.: .40



STATION INDIA

Run No.: NW 310

Wave Height Spectrum

Weather Reporter

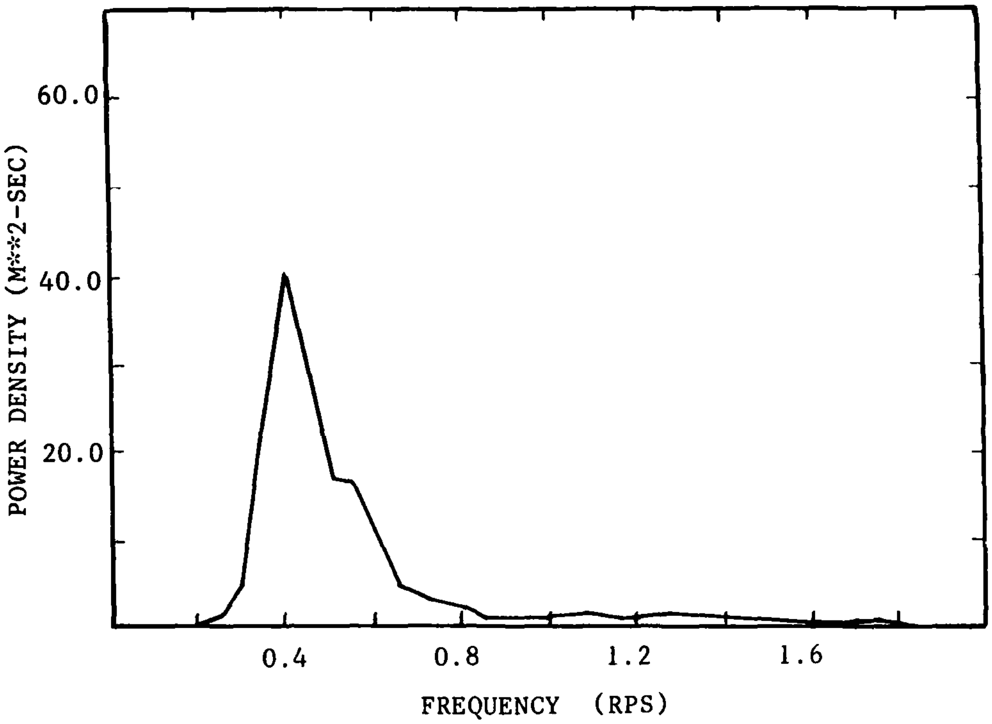
January 26, 1961

Sea State 7 High

Sig. DA: 11.70 M

Amp. Max.: 39.90

Freq Max.: .40



Run No.: NW 320

Wave Height Spectrum

Weather Reporter

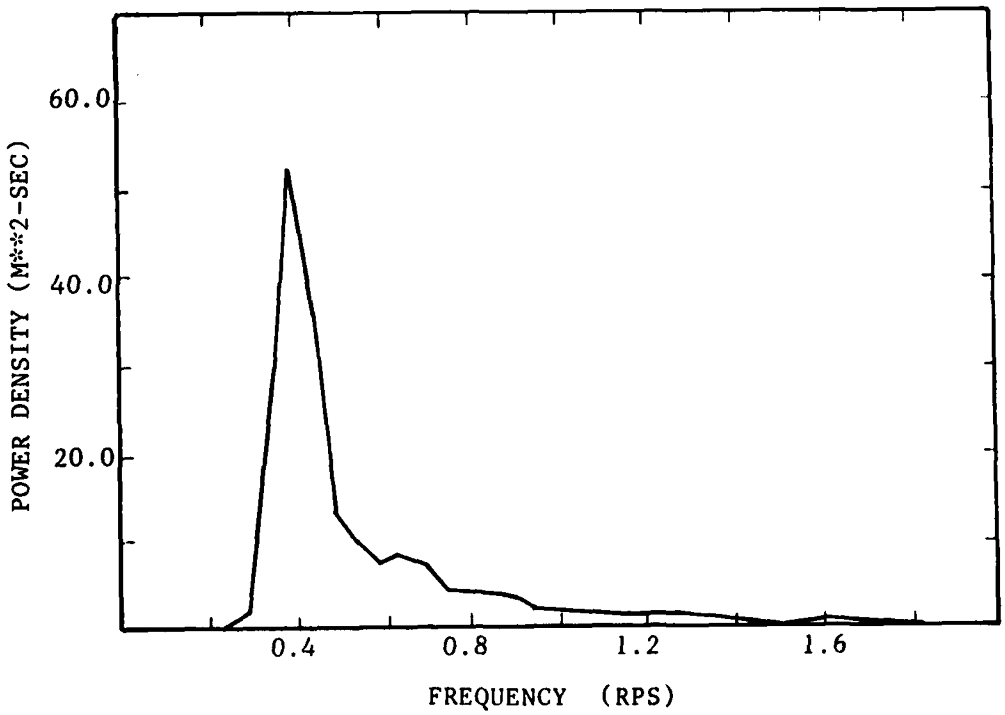
December 8, 1966

Sea State 8 Low

Sig. DA: 12.43 M

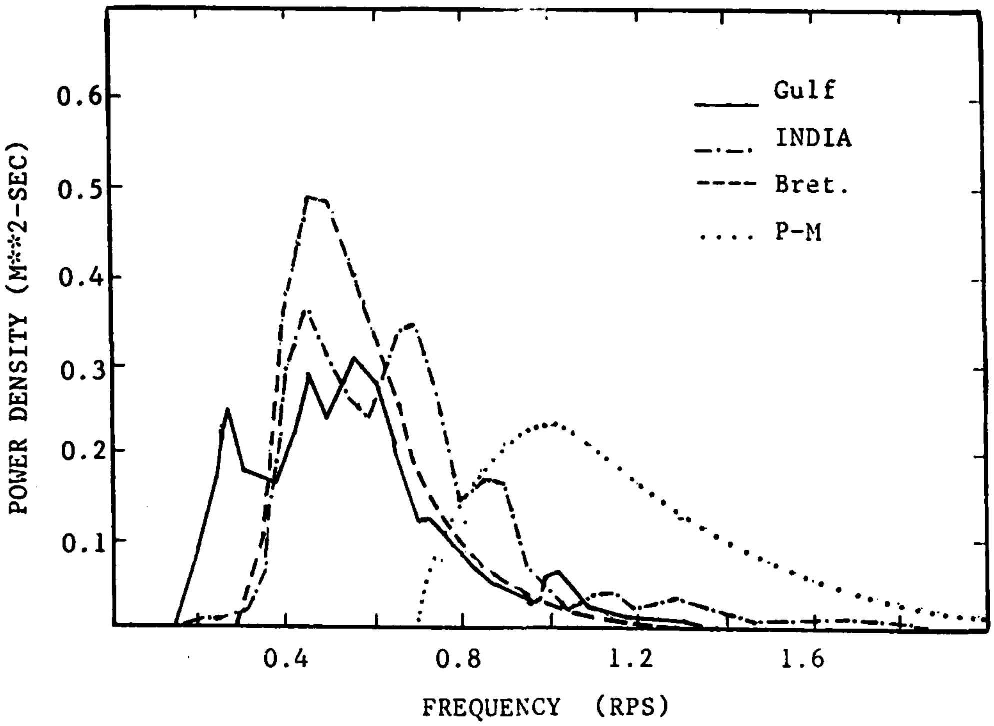
Amp. Max.: 50.63

Freq. Max.: .40

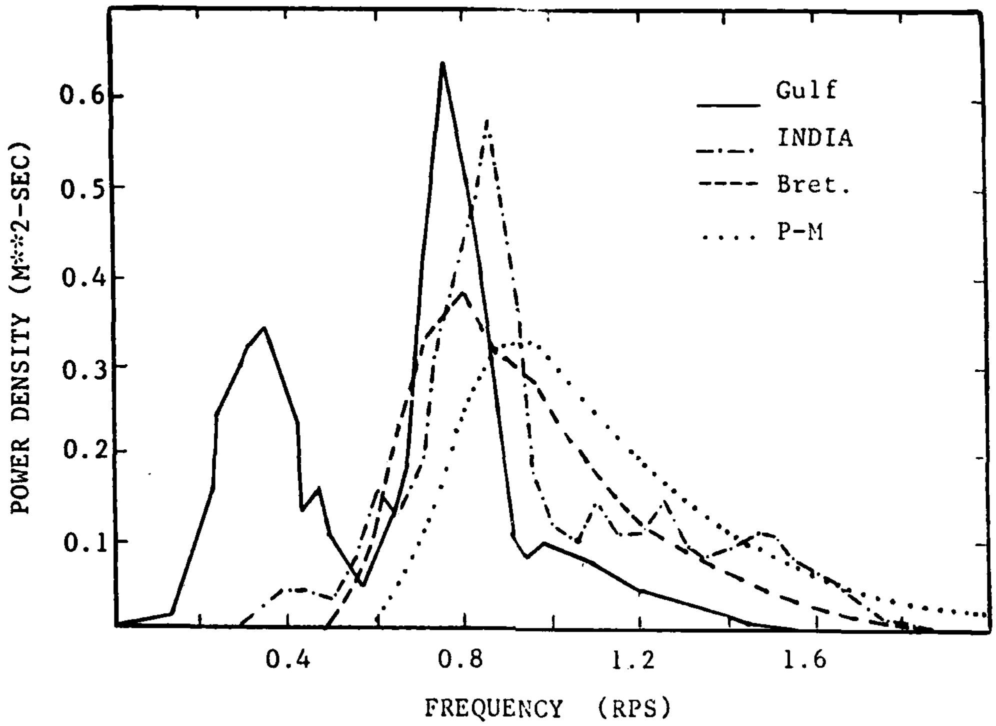


APPENDIX D

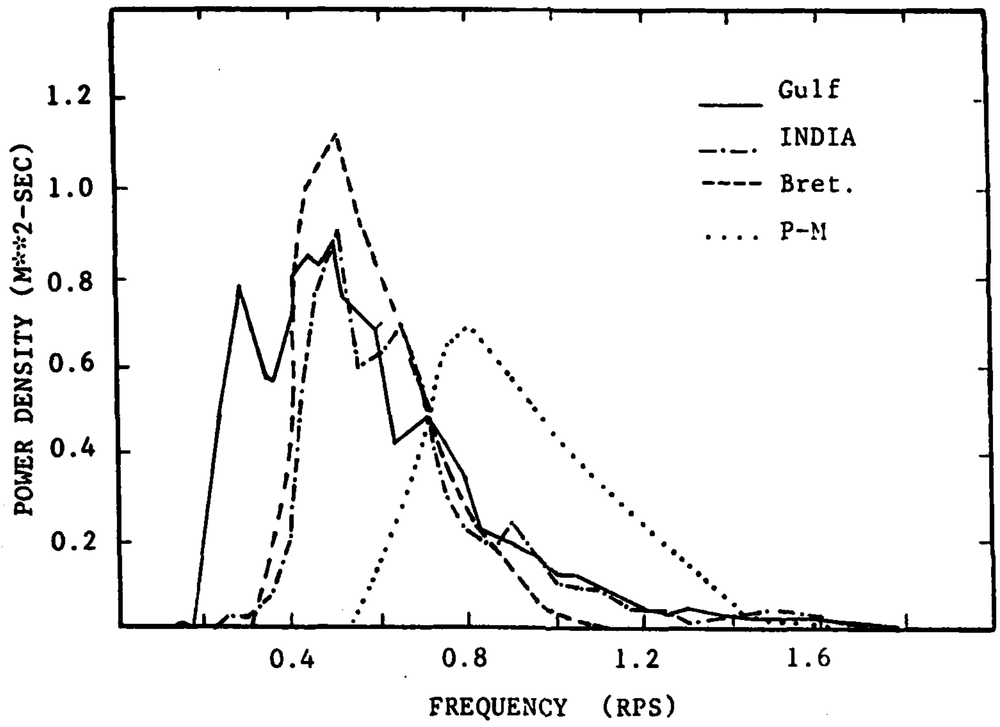
Comparison of Gulf of Mexico, Ocean Station INDIA, Bretschneider and Pierson-Moskowitz Wave Spectra Plots and Statistics



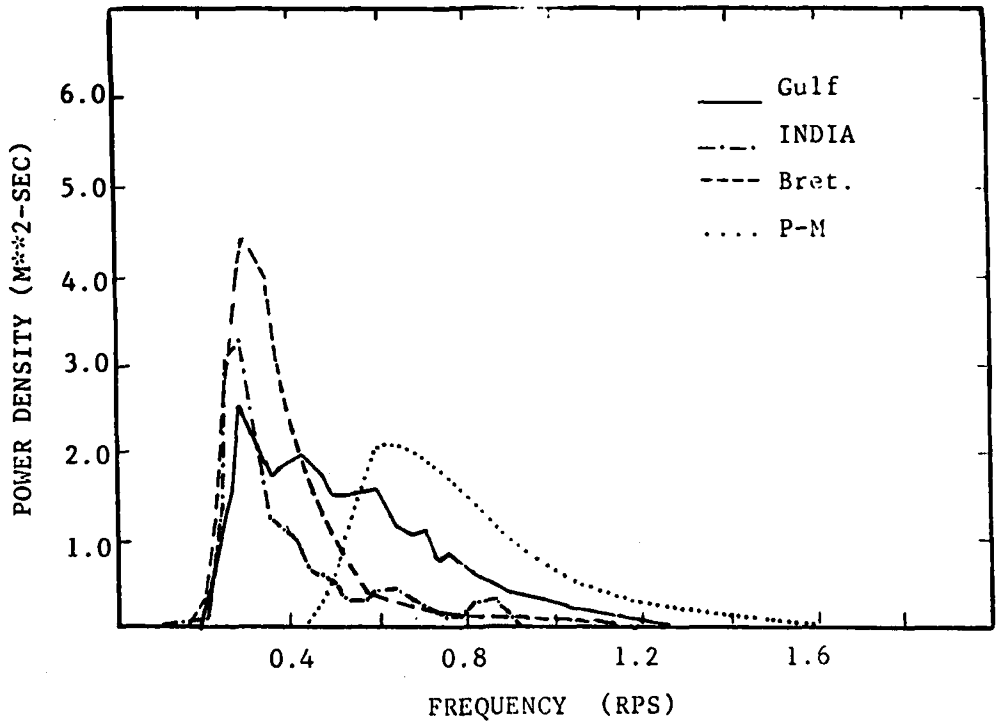
	WAVE HEIGHT SPECTRA			
Location	Gulf, 1 South	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	1600	NW 217	(theoretical)	(theoretical)
Sea State	3 High	3 High	3 High	3 High
Sig. DA	1.58 M	1.64 M	1.61 M	1.56 M
Amp. Max.	0.302	0.36	0.483	0.236
Freq. Max.	0.57	0.45	0.45	1.0



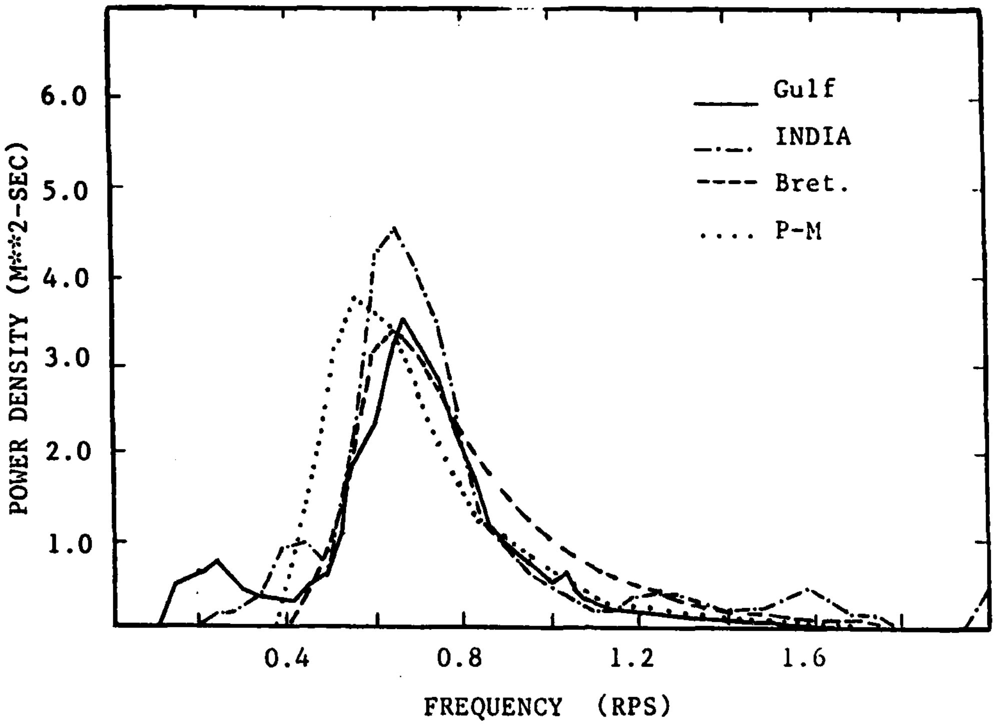
	WAVE HEIGHT SPECTRA			
Location	Gulf, 2 North	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	1	NW 064	(theoretical)	(theoretical)
Sea State	4 Medium	4 Medium	4 Low	4 Low
Sig. DA	1.90 M	1.80 M	1.82 M	1.80 M
Amp. Max.	0.635	0.58	0.387	0.311
Freq. Max.	0.780	0.85	0.80	1.0



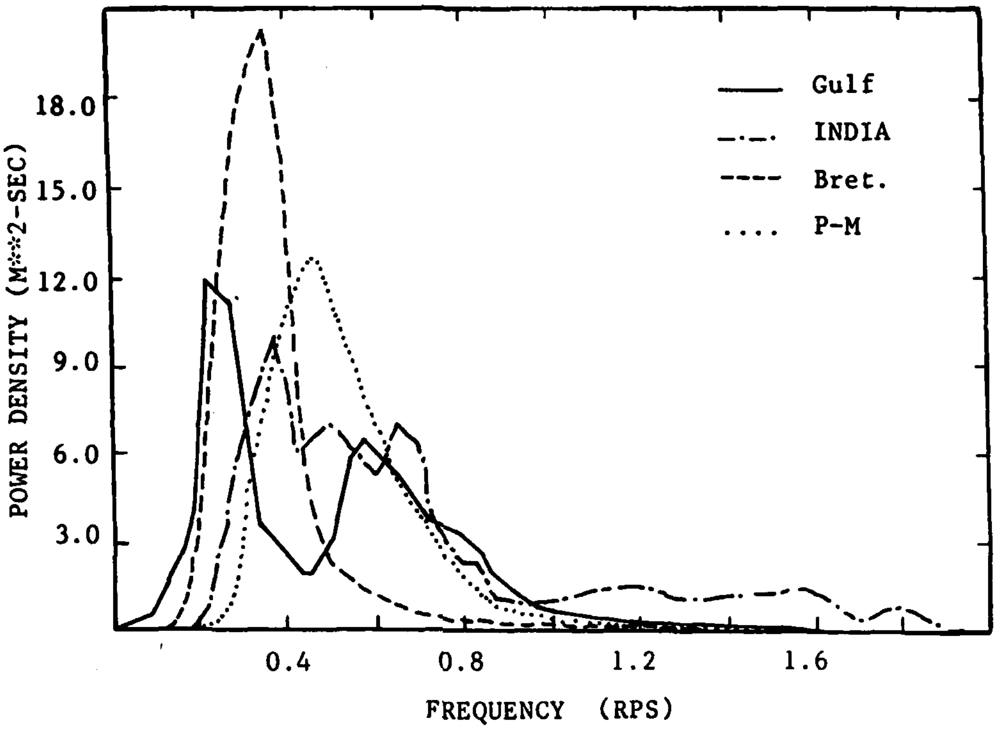
	WAVE HEIGHT SPECTRA			
Location	Gulf, 2 West	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	21600	NW 247	(theoretical)	(theoretical)
Sea State	5 Low	5 Low	5 Low	5 Low
Sig. DA	2.71 M	2.34 M	2.47 M	2.43 M
Amp. Max.	0.898	0.91	1.11	0.683
Freq. Max.	0.497	0.50	0.50	0.80



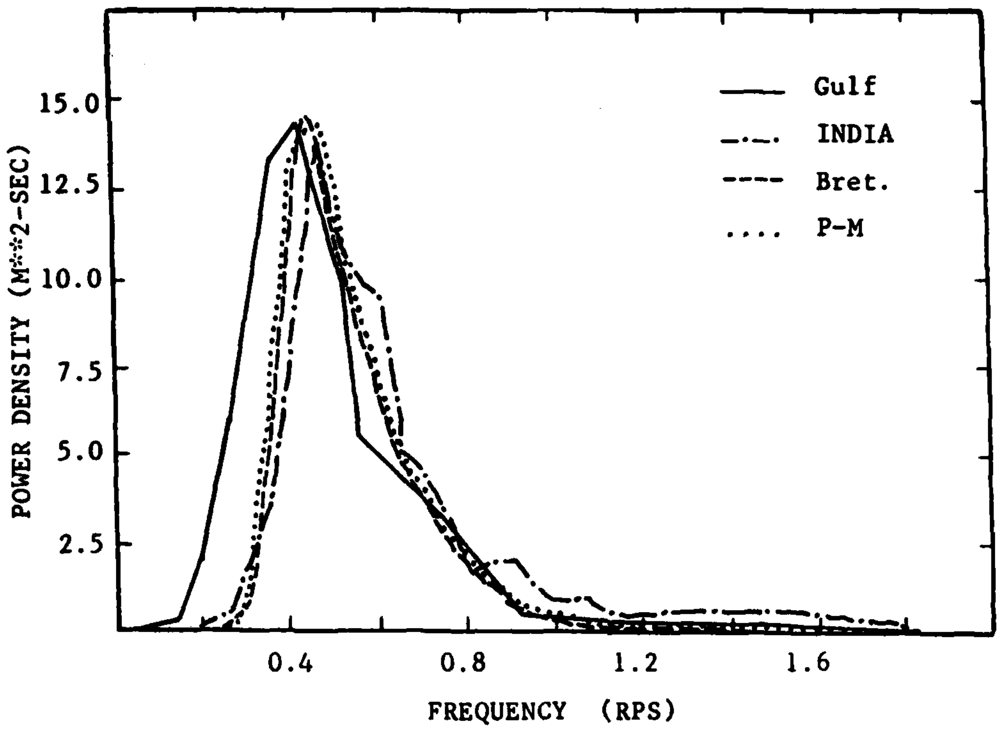
	WAVE HEIGHT SPECTRA			
Location	Gulf, 1 North	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	21600	NW 010	(theoretical)	(theoretical)
Sea State	6 Low	5 High	6 Low	6 Low
Sig. DA	4.06 M	3.70 M	3.87 M	3.85 M
Amp. Max.	2.64	3.30	4.54	2.09
Freq. Max.	0.284	0.30	0.30	0.65



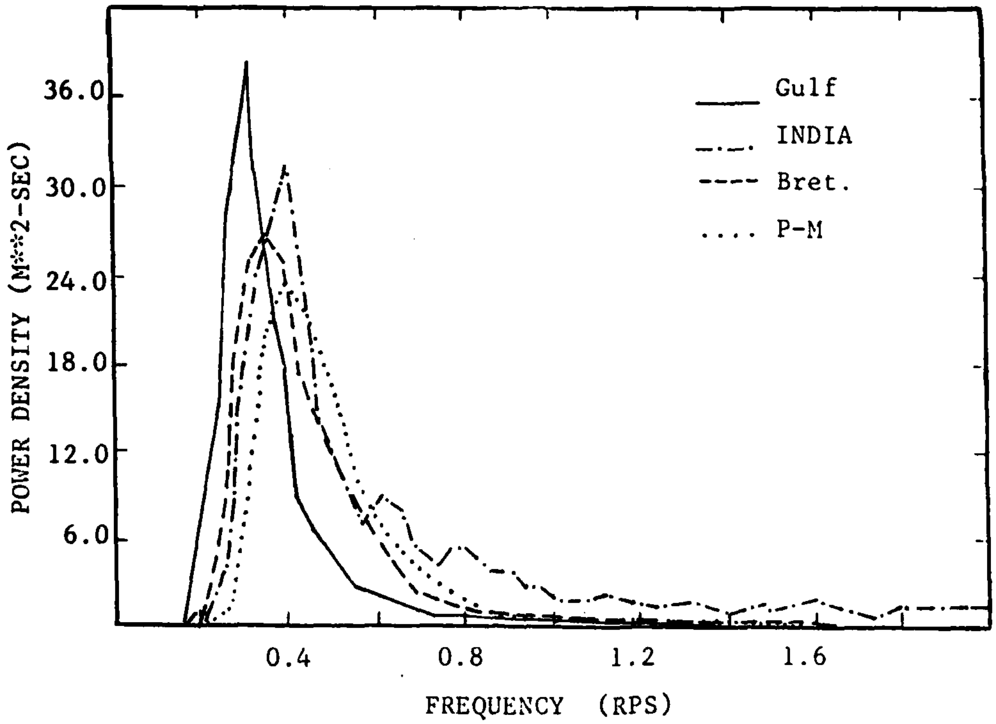
	WAVE HEIGHT SPECTRA			
Location	Gulf, 2 West	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	11900	NW 192	(theoretical)	(theoretical)
Sea State	6 Medium	6 High	6 Medium	6 Medium
Sig. DA	4.75 M	5.04 M	4.85 M	4.90 M
Amp. Max.	3.46	4.59	3.29	3.77
Freq. Max.	0.674	0.65	0.65	0.55



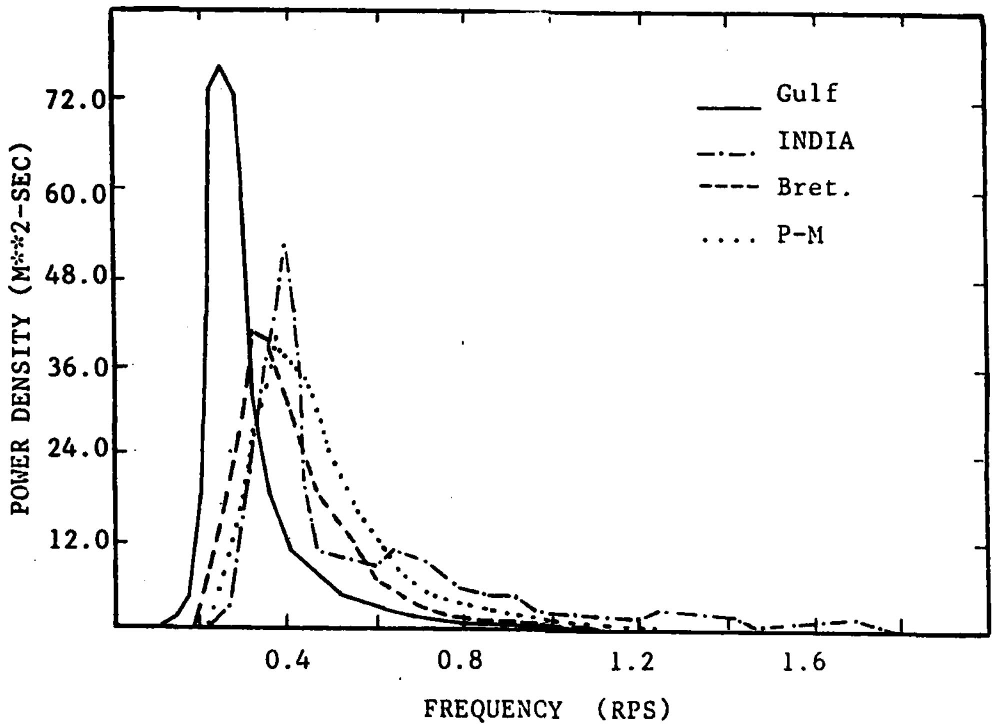
	WAVE HEIGHT SPECTRA			
Location	Gulf, 2 South	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	4100	NW 309	(theoretical)	(theoretical)
Sea State	7 Medium	7 Medium	7 Medium	7 Medium
Sig. DA	8.15 M	8.18 M	8.11 M	8.10 M
Amp. Max.	12.22	10.87	19.78	13.30
Freq. Max.	0.248	0.35	0.30	0.45



	WAVE HEIGHT SPECTRA			
Location	Gulf, 1 East	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	4900	NW 295	(theoretical)	(theoretical)
Sea State	7 Medium	7 Medium	7 Medium	7 Medium
Sig. DA	8.59 M	8.28 M	8.43 M	8.44 M
Amp. Max.	13.29	14.13	14.46	14.55
Freq. Max.	0.426	0.45	0.45	0.45



	WAVE HEIGHT SPECTRA			
Location	Gulf, 2 South	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	11700	NW 149	(theoretical)	(theoretical)
Sea State	7 High	7 High	7 High	7 High
Sig. DA	10.0 M	10.70 M	10.36 M	10.36 M
Amp. Max.	36.41	32.85	27.94	24.52
Freq. Max.	0.284	0.40	0.35	0.40



	WAVE HEIGHT SPECTRA			
Location	Gulf, 1 North	Sta. INDIA	Bretschneider	Pierson-Moskowitz
Run No.	3	NW 320	(theoretical)	(theoretical)
Sea State	8 Low	8 Low	8 Low	8 Low
Sig. DA	12.4 M	12.43 M	12.41 M	12.40 M
Amp. Max.	74.51	52.02	40.46	38.52
Freq. Max.	0.248	0.40	0.30	0.35

APPENDIX E

Operational Procedure

OPERATIONAL PROCEDURE

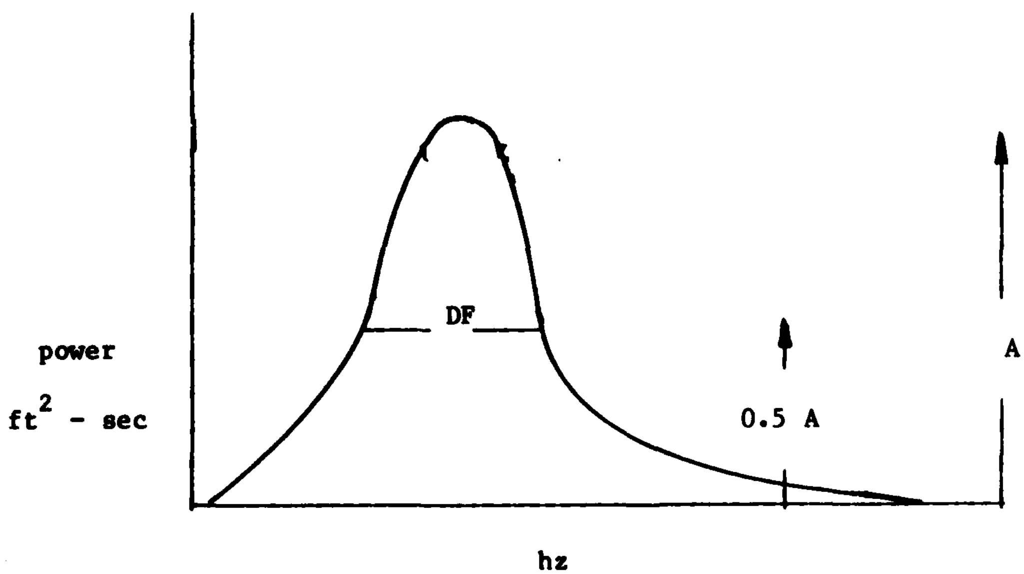
Before a test condition is performed, the time interval of data required to insure a given level of accuracy in the above evaluations should be determined. A good initial approach would be to use the wave height spectrum, which can be obtained before a mission from NCSC's real time spectral analysis of data telemetered from a stage wave gage. An equation for run length determination to assure that the upper bound of the error in the standard deviation estimate is less than η is:

$$T = \frac{8.377}{\eta^2 * DF}$$

where, T = run length (sec)

η = % error as a fraction of 1 (i.e. 5% error would give η = .05)

DF = half - power band width (hertz)



A suggested error level is 5% as in the example. This may seem quite high and the 14% upper bound in the statistical error of the analogous spectral analysis even higher. However, the run times determined in this manner will also be seen to be quite long. It should be noted that the error levels specified here are not actual error levels, but upper bounds to the error levels in the quantity being estimated. This and other more extensive analysis procedures were developed by Rober D. Pierce of the David Taylor Naval Ship R&D Center Central Instrumentation Department.

After motion data has been collected and spectrally analyzed the same techniques can be applied to determine if the motions analyses require a longer period of time than the seaway analysis for a given level of error. In general a narrower spectrum (smaller DF) will require longer periods of time for the same level of error. Care must be taken to coordinate the wave data recorded from the stages and the motion data recorded from the vehicle, in such a way that the wave data represent the waves acting on the vehicle. This includes consideration of: the vehicle location relative to the wave gages, the seaway frequency and directional content, and the vehicle heading and speed. The fact that the vehicle is moving and the wave gage stationary may require offset of and increase in the interval and amount of time respectively of wave data analyzed.

Another operational problem which should be considered when operating in the area of the stages at Panama City is the spacial stationarity of the seaway. Differences between the significant wave heights at the two stages can vary as much as a sea state (model scale) in sea state 1 to 3 conditions.

These conditions are prevalent with off-shore winds where the fetch distance to the outer stage is considerably more than that to the inshore stage 2. This spacial stationarity problem is of course at odds with the previously mentioned long run lengths. A method of avoiding this problem is to make multiple shorter data runs in the same general area when required (one direction and then back and then repeat as required). This avoids to some extent the changes in seaway over much longer distances. The success or failure of such tactics is easily seen in the motion stationarity checks.

Seaway characteristics can be determined the day of the mission using NCSC on-site capabilities. NCSC has in the past done a directional spectrum analysis the morning of a mission. This information coupled with monitoring of the local wind and seaway using NCSC on-line desk-top computer and the real-time-spectral analyzer can provide a fairly complete picture of what can be expected during the mission. Lower frequency waves (swell) can usually be discerned from local wind generated waves using either the directional or real-time spectral analysis. The higher frequency waves in the lower sea states (0 to 1) will be observed, in the directional spectrum analysis to follow, with some lag, the changing wind direction. The highest frequency waves in the spectrum will correspond to the most recent wind direction and vice-versa. The most unidirectional waves will be observed in the higher sea states, however, there will, generally, also be some reflection from the beach.

In summary the following procedures should be followed before and during a seakeeping evaluation mission, and in the data analysis procedures:

Before and During the Mission:

- Use NCSC real time spectrum analyzer and EMS system to determine point spectrum, significant wave height, and seaway spacial stationarity.
- Use NCSC directional spectrum capability to determine seaway directional characteristics (if possible).
- Record water: temperature, salinity, and depth.
- Record current: velocity and direction (on model if possible).
- Record wind: speed and direction (on model if possible when surfaced).
- Operate in vicinity of environmental monitoring transducers.
- Determine the required run length for given accuracy level.
- Maintain constant heading relative to waves (except for maneuvering in waves runs)
- Maintain constant depth (except in diving and surfacing in wave conditions).

Seakeeping Data Analysis Procedures:

- Evaluate the spacial and temporal stationarity of the seaway.
- Determine the seaway directionality, amplitude, and frequency relative to CSTV.
- Evaluate the temporal stationarity of the vehicle propulsion, controls, and motions.
- Perform frequency and time domain analysis of seaway and motions.

- If seaway is unidirectional calculate response amplitude operators and/or transfer functions from the seaway and motions spectra.

The seakeeping evaluation method discussed above provide a means of qualifying and quantifying those wave and current forces acting upon a test vehicle. Operation of an experimental vehicle in a seaway that qualifies as: temporally and spacially stationary, unidirectional, and which reasonably approximates the desired spectral distribution; provides for easier comparison with idealized full scale and theoretical studies. Operation of an experimental vehicle in multidirectional seaways presents a difficult situation in terms of comparing results. This same situation is generally encountered with actual full scale trial results where multidirectional seaways are generally prevalent.

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